Integrated semantic processing of complex pictures and spoken sentences – Evidence from event-related potentials

Psykologian Pro Gradu -tutkielma (49 s + 8 ls)

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Abstract

It has been suggested that semantic information processing is modularized according to the input form (e.g., visual, verbal, non-verbal sound). A great deal of research has concentrated on detecting a separate verbal module. Also, it has traditionally been assumed in linguistics that the meaning of a single clause is computed before integration to a wider context. Recent research has called these views into question. The present study explored whether it is reasonable to assume separate verbal and nonverbal semantic systems in the light of the evidence from event-related potentials (ERPs). The study also provided information on whether the context influences processing of a single clause before the local meaning is computed.

The focus was on an ERP called N400. Its amplitude is assumed to reflect the effort required to integrate an item to the preceding context. For instance, if a word is anomalous in its context, it will elicit a larger N400. N400 has been observed in experiments using both verbal and nonverbal stimuli. Contents of a single sentence were not hypothesized to influence the N400 amplitude. Only the combined contents of the sentence and the picture were hypothesized to influence the N400.

The subjects (n = 17) viewed pictures on a computer screen while hearing sentences through headphones. Their task was to judge the congruency of the picture and the sentence. There were four conditions: 1) the picture and the sentence were congruent and sensible, 2) the sentence and the picture were congruent, but the sentence ended anomalously, 3) the picture and the sentence were incongruent but sensible, 4) the picture and the sentence were incongruent and anomalous. Stimuli from the four conditions were presented in a semi-randomized sequence. Their electroencephalography was simultaneously recorded. ERPs were computed for the four conditions.

The amplitude of the N400 effect was largest in the incongruent sentence-picture -pairs. The anomalously ending sentences did not elicit a larger N400 than the sensible sentences. The results suggest that there is no separate verbal semantic system, and that the meaning of a single clause is not processed independent of the context.

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1 Introduction

In addition to sensorimotor processes necessary for our navigation in the physical environment we also constantly process higher-level information related to the current situation. Thought, by encyclopedic definition, refers to our capability to model the world, and so to deal with it effectively according to our goals, plans, and desires. Thinking involves manipulation of information, as when we form concepts, engage in problem solving, and make decisions. The role of language in processing of higher-level information has long been appreciated. Some might say that our capability to think lies exclusively on language, and that humans differ fundamentally from other species in thought processes. But animals too can think or, at least, solve problems creatively.

Primates and marine mammals have been particularly competent in problem solving experiments. Species of these biological orders often have highly developed communication systems. Problem solving capabilities and language seem to have evolved hand-in-hand but causal relations remain unsolved. Does one cause the other or, perhaps, are both caused by a third factor (e.g., growth of brain areas responsible for locomotion). There is no doubt that language has lifted our mental capacity to a different level. What remains debatable is whether the emergence of the language faculty came with a new, apparatus for thinking not seen in other species (for a discussion, see Fitch, Hauser, & Chomsky, 2005; Hauser, Chomsky, & Fitch, 2002; Jackendoff & Pinker, 2005; Pinker & Jackendoff, 2005).

In a natural environment, verbal, visual, and other sensory information is constantly processed and integrated in a flowing manner. We follow the eye movements, facial expressions, and hand gestures of our company to help disambiguate the verbal messages (e.g., Ekman & Friesen, 1969; McNeill, 1992), and because of this, we do not have to speak unambiguously. For instance, written transcription of a cocktail party conversation between two persons might be incomprehensible without the visual referents. Of course, a recording of the same conversation would be even more difficult to comprehend because of difficulties involved in the identification of single phonemes (McGurk & MacDonald, 1976) and clauses (Wright & Wareham, 2005). The expected language input is usually restricted by world knowledge, other sensory environment, and the preceding linguistic context. Even so, some theories suggest that before integration within a wider context, language comprehension first takes place at sentence and clause levels drawing only from long-term semantic memory.

It is possible for us to run into situations that are anomalous or that might even seem impossible on the basis of our previous experience and knowledge. Fortunately, people are usually fast to adapt to new situations. For instance, we are not constantly puzzled when visiting Disneyland and talking about cartoon characters as real persons, or when we are reading a fairy tale. This kind of phenomena are in line with situationist models that posit that we do not try to integrate linguistic input directly with crystallized semantic memory contents, but with a current mental model in a so-called long-term working memory (Zwaan & Radvansky, 1998).

In the present study, subjects are provided a visual context that consists of pictures depicting sensible and anomalous events. The subjects will simultaneously hear spoken sentences that are either congruent or incongruent with the visual context. The aim is to find out how independently the sentences are processed before interaction with the visual context. The findings will be discussed in relation to theories that emphasize the existence of a separate language processing unit and to theories that assume that in language comprehension a local semantic meaning of a sentence is always computed before integrating it into a wider context.

Semantic processing is reflected by the brain's electrical activity recorded on the surface of the scalp. The focus is on a well known electrical brain response called N400 that reflects semantic compatibility and relatedness between a stimulus and the preceding context (Kutas & Federmeier, 2000). The hypothesis is that processing of visual and verbal semantic information takes place in a unitary system, and that local meaning does not have to be computed before contextual integration. This is expected to be manifested in the electrical brain activity as no difference between the sensible and anomalous sentences, but a difference between the congruent and incongruent sentence-picture pairs.

1.1 Local and global levels in language comprehension

In linguistic theories of how sentences encode meaning, a distinction is often made between a rule-based meaning of a single sentence (semantics), and a meaning that emerges when the sentence is integrated within a wider context (pragmatics). In psycholinguistics, the interplay between these two has been discussed in terms of "local" and "global factors" (e.g., Hess, Foss, & Carroll, 1995). An important topic has been when and how these levels interact (e.g., Carpenter, Miyake, & Just, 1995; Graesser, Millis, & Zwaan, 1997; McKoon & Ratcliff, 1998). It has been traditionally assumed in linguistics that a context-independent semantic meaning of a clause or a sentence is computed first and then integrated into a wider context (e.g., Fodor, 1983; e.g., Millis & Just, 1994; van Dijk & Kintsch, 1983). These "two-step" models have been challenged by more interactive models of language comprehension in which processing of local meaning has no temporal or functional precedence over processing of the pragmatic and contextual meaning (e.g., Jackendoff, 2007; MacDonald, Pearlmutter, & Seidenberg, 1994; Marslen-Wilson & Tyler, 1980; Trueswell & Tanenhaus, 1994)

It has also been questioned if language faculty is an independent cognitive module at all. Cognitive linguistics is a field of linguistics that approaches language and cognition without making modular distinctions between language faculty and other cognitive functions (Croft & Cruse, 2004). In cognitive semantics, a verbally transmitted meaning is not independent of perception (e.g., Gärdenfors, 1999). A central hypothesis in cognitive semantics is that word meanings and sensory percepts are stored in the same form as suggested by the fact that we can easily talk about what we see, and imagine what we are talked about (Gärdenfors, 1999).

Eye movement studies have provided evidence that syntactic processing is influenced by what one sees before the sentence is completed. Tanenhaus, Spivey-Knowlton, Eberhard, and Sedivy (1995) had their subjects manipulate objects according to verbal instructions while their eye movements were being recorded. On hearing a sentence such as, "put the apple on the towel in the box", English speaking listeners usually first interpret "on the towel" as the destination. When the scene included one apple on a towel, and also an empty towel, subjects usually guessed wrong as expressed by a saccade to the empty towel. When another apple was added to the scene (on a napkin) the subjects readily interpreted "on the towel" as modifier instead of destination. This was evidenced by, first a saccade to an apple that was on the towel, and then to the box, skipping the saccade to the empty towel. The authors argued that "if initial syntactic processing was encapsulated, as modular theories claim, then people should still initially interpret 'on the towel' as destination". These findings have been interpreted as evidence showing that at least a part of syntactic processing has a visuospatial grounding that can be accessed by verbal input as well as visual perception (Jackendoff, 2007). Since Tanenhaus et al. (1995), other eye-tracking experiments have confirmed that syntactic and semantic processing are influenced by the visual scene at an early phase (Altmann & Kamide, 1999; Kamide, Altmann, & Haywood, 2003; Spivey, Tanenhaus, Eberhard, & Sedivy, 2002).

Situationist models of language comprehension (Garnham, 1981; Johnson-Laird, 1983; Kintsch, 1988; van Dijk & Kintsch, 1983; Zwaan & Radvansky, 1998) have a central tenet that language comprehension is aided by a mental model of the situation that is dealt with. They also assume that language input is processed on the global and local levels simultaneously (except for the model of van Dijk & Kintsch). When a person hears a sentence, it is assumed that he constructs a mental model on the basis of semantic meaning of incoming words and previous knowledge. The next sentence on the same topic would also be processed in relation to the established mental model. Mental model construction does not have to wait until an unambiguous interpretation is possible, instead, the relations of the activated meaning units and actors can be rearranged as more information is perceived (Zwaan & Madden, 2004). An illustration of a mental model construction is provided in figure 1.

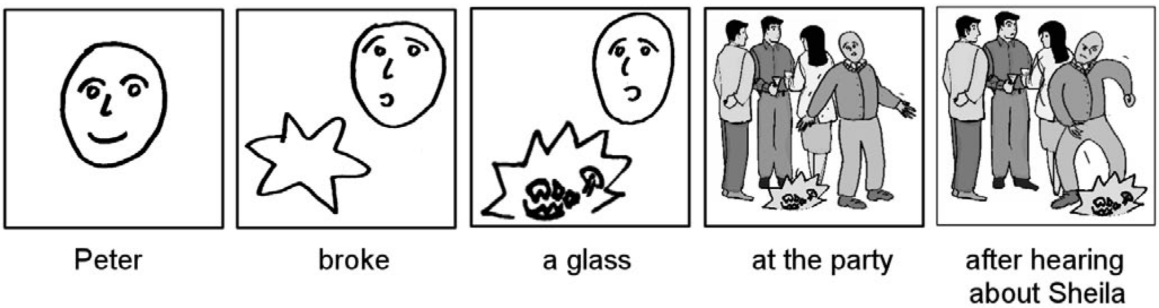

Figure 1: Illustration of a mental model construction. Meaning units are activated and their relations are established on the basis of the unfolding auditory stream and prior knowledge. The mental model remains open for continuous updating. (It is not proposed that the representation of a mental model is an image in mind but the representation can intentionally be visualized or verbalized (see Pylyshyn, 1973, 2003).)

After one person has told another about an event he has seen, the listener may share at least part of the mental model of the speaker. Even ambiguous following comments such as “Guess what Mark did?” would rapidly further unify the mental models of the describer and the listener if they share the same impression about Mark.

In the example above, the describer has no trouble answering any questions because he was there and grasped the essence of the situation in a few glimpses. How is the process of comprehension different for the eyewitness and the listener? Do the long term memory representations of the witness and the listener differ in representation form?

1.2 Unitary and multiple semantics theories

The issue of how information is stored and represented in the semantic memory has long been studied in cognitive science (e.g., Rogers et al., 2004). A great deal of debate has centered around whether the semantic memory is organized around sensory modalities (e.g., Shallice, 1988), or not (e.g., Humphreys & Riddoch, 1988). Although language is not a sensory modality the multiple semantics debate has centered around a hypothesis that verbal information is stored and processed in a separate semantic system (Paivio, 1971). Independent verbal semantics has been discussed particularly in contrast to visual semantics.

Caramazza, Hillis, Rapp, and Romani (1990) tried to clarify the still ongoing debate about the modularity of semantic processing. They distinguished two main families of theories: 1) *Multiple semantics*: Linguistic and nonlinguistic semantic information differ in their representation form and way of processing. There may be many modality specific semantic systems. 2) *Unitary semantics*: All meaning-level information is represented in a unitary form and is processed in a unitary system (with separate interfaces to linguistic and nonlinguistic percepts).

Figure 2 illustrates the differences of unitary semantics and multiple semantics theories. The unitary semantics model follows the Organized Unitary Content Hypothesis (OUCH) of Caramazza et al. (1990), and the multiple semantics model follows the dual-coding hypothesis of Paivio (1986, 1991). In both models, a nonlinguistic representation activates more information and faster because a percept of a real object or scene always comes with

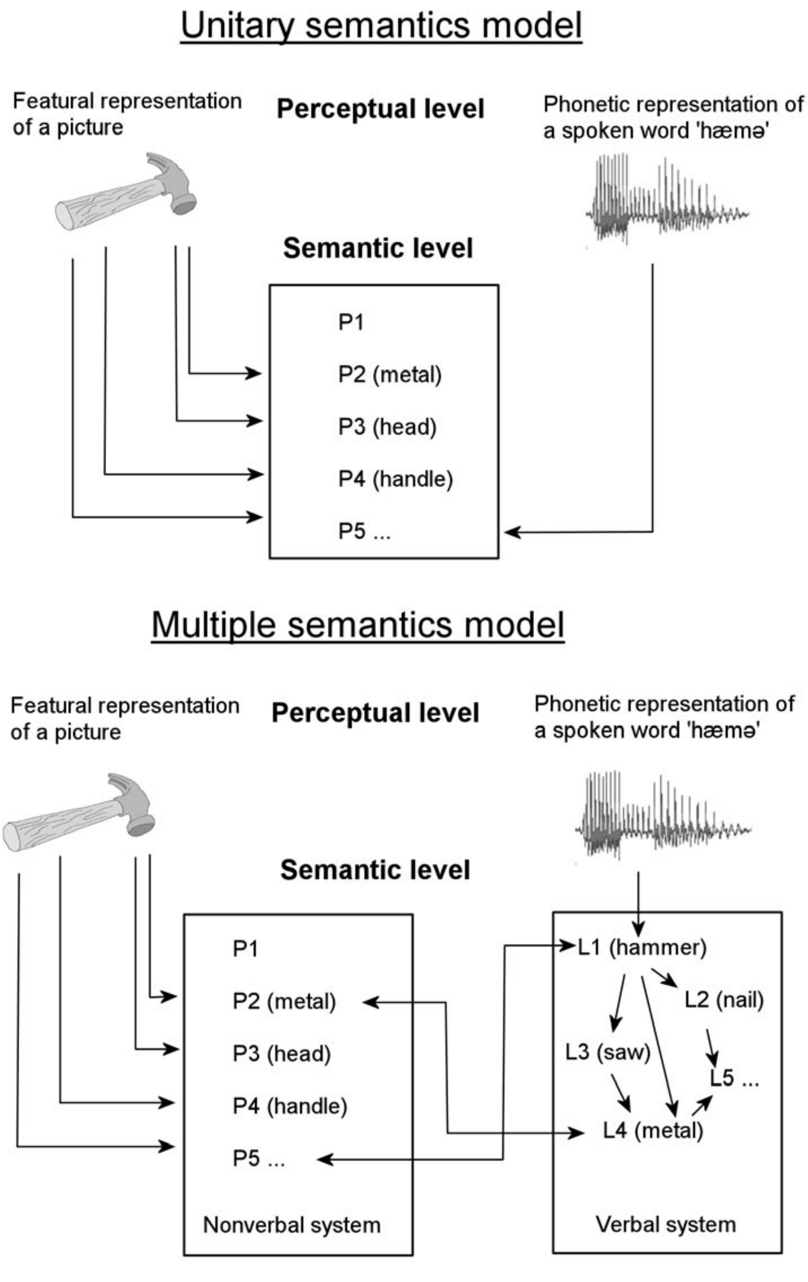

Figure 2: Unitary semantics and multiple semantics illustrated. In both models, perception of visual objects activates directly various related attributes, and words only the core concept. In the multiple semantics model, the concept of a word is within the verbal system where it is able to activate other linguistic meaning units and meaning units in the nonverbal system. In the unitary semantics model, the linguistic meaning unit of a concept is stored in the same system as its physical attributes.

perception of a variety of related attributes. Words are more or less random symbols for certain meanings and are thus able to activate associated attributes and concepts only after recognition. For instance, the fact that pictures are categorized faster than words (e.g., Friedman & Bourne, 1976; Potter & Faulconer, 1975; Seifert, 1997) can be explained with this assumption: categorization must be preceded by activation of conceptual information and pictures activate related semantic information directly but words only after a sequential process.

In the unitary semantics model, verbal and nonverbal semantic information are processed in the same system but there may be differences in behavioral performance and brain imaging results because the form of the input causes differences in the initial activation patterns of the conceptual knowledge. In unitary semantics hypotheses such as the OUCH (Caramazza et al., 1990), and the context-availability hypothesis by Bransford and McCarrell (1974) and Kieras (1978), processing of linguistic and nonlinguistic information differ mainly in the speed of access. It takes time and many words to transfer information that can be seen in one glimpse.

In the multiple semantics model, the systems process information in different ways: the nonverbal system is specialized for synchronous and parallel processing and the verbal system for sequential processing (Paivio, 1986). The multiple semantics model excludes any mediating common-code system in the name of parsimony (Paivio, 1986). Verbal information is stored in a fundamentally different form, is processed in different computations, and is in interaction with the nonlinguistic system only by simple associations. For example, planning a route to a desired geographical location would perhaps be done in the visual system, but planning an excuse for a missed appointment would be done in the verbal system.

The unitary semantics proponents have long proposed that instead of sensory modalities and language domain, the semantic memory is organized over naturally occurring categories (e.g., animal, fruit, tool; Capitani, Laiacona, Mahon, & Caramazza, 2003). Recently, it has also been suggested that the brain-damaged patient data and brain imaging data on semantic memory organization are best accounted for by a semantic memory model that is organized over specific attribute domains (e.g., grabbable, loud, used in construction) rather than naturally occurring categories or sensory domains (Tyler & Moss, 2001; see Thompson-Schill, Kan, & Oliver, 2006, for a review over the supporting brain imaging evidence). In this account, concepts are represented as patterns of activation over multiple semantic properties within a unitary distributed system (Tyler & Moss, 2001).

Allegorically, long-term memory anatomy does not have to influence semantic processing as the exact placing of different ingredients does not have to influence the act of cooking. Perhaps it is not the same to have misplaced a spice, and to have water cut in the neighborhood. However, the problem solving would essentially be the same: get it somewhere else, leave it out, or replace it with something else. Neuropsychological patient data and hemodynamic studies might not be able to solve the unitary-multiple semantics debate. Fortunately, new evidence is emerging for instance from the event-related potentials studies (e.g., Holcomb, Kounios, Anderson, & West, 1999).

1.3 Electroencephalography

In electroencephalography, electrical activity of the brain is recorded from electrodes placed on the scalp or, in special cases, subdurally or in the cortex. The power spectra of EEG signals recorded on the scalp mainly reflects synchronous activity of groups of cortical pyramidal cells whose dendrites are organized in palisades (e.g., Nunez & Srinivasan, 2006); the dendrites of other cell types are considered to have a radial (relative to the soma) or a random (relative to the other cells) orientation, which prevents even synchronized electrical activity from reaching the scalp. In the standard model, the EEG signals are produced by compact regions of cortex whose post-synaptic activity is synchronized and the electrical fields are similarly oriented by cortical geometry (Makeig, Debener, Onton, & Delorme, 2004). This traditional view has recently been challenged by more complex models (Freeman, Burke, & Holmes, 2003; Suffczynski, Kalitzin, Pfurtscheller, & Lopes da Silva, 2001; Wright et al., 2001).

The main virtue of EEG is its excellent temporal resolution, and the most prominent shortcoming its poor spatial resolution. EEG signals reach the scalp by volume conduction. The scalp-recorded EEG is a very large scale measure of brain activity in centimeter and even whole-brain scales. Hard and soft tissues inside the head smear the scalp recorded electric fields of separate sources. Computerized disentanglement and signal source localization is complicated and error-prone because: 1) there is individual variation in the amounts and conductive properties of hard and soft tissues, 2) there is individual variation in the setting of gyri and sulci, and 3) there is often only hypothetical knowledge about the number of neural generators contributing to the recorded EEG signal. (Nunez & Srinivasan, 2006)

Raw (unprocessed) EEG has poor signal-to-noise ratio (Nunez & Srinivasan, 2006). The noise is mainly caused by muscle activity and external electrical fields (e.g., Jung et al., 2000). The electrical field produced by muscle activity of, for instance an eye blink, is far greater than the field produced by a population of cortical neurons. Variation in task strategies adopted by the subjects can also produce noise but is possible to control by careful setting of the experimental conditions. For these reasons, experimental scientists have typically studied averaged EEG traces (Nunez & Srinivasan, 2006).

1.4 Event-related potentials

Studying event-related potentials (ERPs) has been the most common approach in experimental research utilizing EEG recordings (Nunez & Srinivasan, 2006), although recently there has also been a growing interest in event-related effects in specific frequency bands (e.g., Kutas, Federmeier, & Sereno, 1999), and in patterns of change across many sub-bands (e.g. Makeig et al., 2004). An ERP is a record of electrical brain activity associated with a specific event (usually a stimulus). ERP components produced by the brain processes in focus are usually too small to be detected from a single scalp-recorded ERP because of background brain activity and non-neuronal electrical noise (Nunez & Srinivasan, 2006). The signal-to-noise ratio is increased by averaging many ERPs time-locked to the same event type. ERPs are visualized as series of positive and negative deflections whose amplitudes, latencies, and topographical distributions are the subjects of interest (e.g., Kutas et al., 1999; fig. 3).

The logic of the ERP technique in studying cognition is twofold (Hinojosa, Martin-Loeches, & Rubia, 2001): On the one hand, ERP components are linked to certain cognitive processes, localized, and possibly, dissected into subcomponents. On the other hand, the presence and characteristics of a well-established ERP component tells about the cognitive processes associated with the experimental conditions. This straightforwardness is hindered by the fact that almost any finding can be suggested to tell about the cognitive process or the ERP component. For instance, if an ERP component is absent in an experimental condition, the scientist may suggest that the cognitive processes previously associated with the specific ERP did not occur, or, it is possible to claim on other grounds that the processes were present but the ERP is actually not sensitive to those processes.

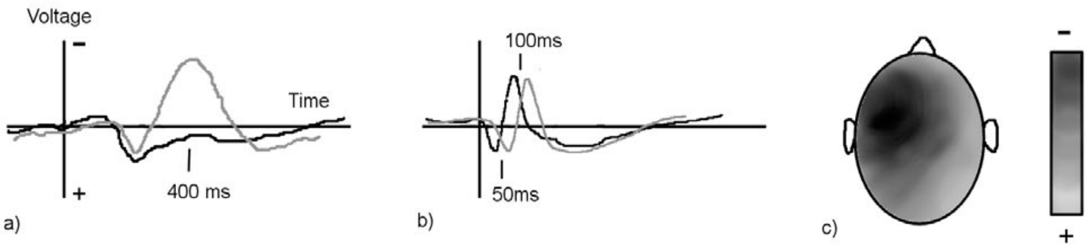

Figure 3: illustrations of ERP effects. a) Amplitude difference in a component that is called N400 (it peaks around 400 ms after stimulus onset and is a negative deflection), b) a latency difference in components called P1 and N1, c) scalp topographical representation of activity in a certain time window showing a left anterior negativity. (A common procedure is also to subtract one waveform from another and show the subtraction waveform.)

1.4.1 Early ERP effects to speech

Auditory ERP components called P1 (aka P50) and N1 (aka N100) precede the lexical and semantic ERPs. In connected speech, the P1 and N1 are usually attenuated or even impossible to detect (e.g., Connolly, Phillips, Stewart, & Brake, 1992; Connolly, Stewart, & Phillips, 1990; Friederici, Pfeifer, & Hahne, 1993; O'Halloran, Isenhart, Sandman, & Larkey, 1988), possibly because there is no silence before the onset of the target word (O'Halloran et al., 1988), or because of inaccuracy in the time-locking (Sanders & Neville, 2003). Some studies, however, have reported P1 and N1 effects even to continuous speech (Holcomb & Neville, 1991; Sanders & Neville, 2003). It is possible that the proportion of plosive consonants (e.g., k, p, & t) in the target words, or the accuracy of the time-locking defines the amplitudes of the P1 and the N1. In order to avoid confounding effects of these early non-semantic auditory ERPs it is important to keep the acoustic properties of the target words similar across different conditions.

1.5 N400 effect

The N400 is an ERP component that was first observed as a response to semantically anomalous words in written sentence contexts (e.g., "I like my coffee with cream and dog"; Kutas & Hillyard, 1980). It is a negative deflection between 250 and 600 ms, peaking around 400 ms after stimulus onset (Kutas et al., 1999). The most widely accepted view of the N400 is that its amplitude reflects 'contextual integration' and mental effort required to integrate an item into context (e.g., Holcomb, 1993; Kutas & Federmeier, 2000). It is also sensitive to the ease of accessing information from the long-term memory as reflected by smaller amplitudes to more frequent or repeated isolated words. However, this effect disappears when the words are placed in a supportive semantic context (Van Petten, 1993; Van Petten & Kutas, 1990, 1991). Although the N400 is especially large to semantic and contextual violations, it is a normal response words and pseudowords in any context (Kutas & Federmeier, 2000).

The N400 is not only sensitive to semantic anomaly within a sentence, but also to semantic relatedness of pairs of words, coherency of larger narratives, and even to global truth value of a sentence. For instance, if a word '*west*' is primed by '*east*', it elicits smaller N400 than it would if it was primed by '*dog*' (Bentin, McCarthy, & Wood, 1985). If the sentence, "Jane told her brother that he was exceptionally *quick/slow*", was preceded by a narrative about the brother doing something very quickly, then the word '*slow*' would elicit a larger N400 (Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; van Berkum, Hagoort, & Brown, 1999; van Berkum, Zwitserlood, Hagoort, & Brown, 2003). A sentence such as, "The Dutch trains are *white* and usually very crowded" is not true according to a Dutch subject's world knowledge. The Dutch trains are yellow and consequently '*white*' elicits a larger N400 than '*yellow'* (Hagoort, Hald, Bastiaansen, & Petersson, 2004).

In addition to written or spoken words, N400-like components to unexpected items have also been reported in response to, at least, environmental sounds, drawings, photographs of faces and objects, cartoon strips, videos, and number series. In addition, odor primes have been successful in modulating N400 to target pictures. The nonverbally elicited N400 appears in most studies to have slight differences in the scalp distribution when compared with the "verbal" N400 (e.g., Van Petten & Luka, 2006). However, there is also variation in the scalp distributions in studies using verbal materials (e.g., Domalski, Smith, & Halgren, 1991; Holcomb et al., 1999; Holcomb & Neville, 1990), and some studies have reported very similar scalp distributions for nonverbal and verbal N400s (Cummings et al., 2006; Nigam, Hoffman, & Simons, 1992; Plante, Petten, & Senkfor, 2000).

Because the scalp distribution of the N400 in the most studies has differed depending on the task and the stimuli used, it is assumed to reflect coordinated activity at multiple brain areas (Kutas & Federmeier, 2000). The contribution of each of the neural generator depends on the task and stimulus properties (Holcomb et al., 1999; Kounios, 1996; Nobre & McCarthy, 1994). Additional evidence for the involvement of multiple neural generators is provided by intracranial EEG recordings (e.g., McCarthy, Nobre, Bentin, & Spencer, 1995; Nobre & McCarthy, 1995), studies utilizing functional magnetic resonance imaging (fMRI; e.g., Cardillo, Aydelott, Matthews, & Devlin, 2004; Kuperberg et al., 2003; Postler et al., 2003), positron emission tomography (PET; e.g., Bright, Moss, & Tyler, 2004; Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996), magnetoencephalography (MEG; e.g., Halgren et al., 2002; Maess, Herrmann, Hahne, Nakamura, & Friederici, 2006; Pylkkänen & Marantz, 2003), and brain-damaged patient studies (e.g., Friederici, von Cramon, & Kotz, 1999; Hagoort, Brown, & Swaab, 1996; Hagoort, Wassenaar, & Brown, 2003). It is not clear, however, whether the differences in scalp distributions arise from pre-semantic or semantic processing. Clarifying this distinction is one of the aims of the present study.

1.5.1 N400 to speech

The N400 effect can be detected to context incongruent words in the middle or at the end of a sentence. In comparison to the N400 evoked by written input, the N400 to spoken words tends to be earlier in onset and peak, larger in amplitude, and longer in duration (e.g., Holcomb & Neville, 1990; van Berkum et al., 2003), and sometimes has a more anterior distribution (e.g., Domalski et al., 1991). The temporal smearing of the auditory N400 has multiple candidates for explanation (see e.g., van Berkum et al., 2003): there may be inaccuracy in the time locking, or phonemic variation in the preceding word that contains information about the next word, or the unfolding nature of a spoken word may cause a series of semantic integration attempts when compared to written words that are recognized at once.

Also, varying recognition and isolation points in spoken words may be behind this smearing. Recognition point refers to the point in the acoustic signal at which the subjects agree on the word identity and are confident about it. Isolation point is the point at which most subjects guess the word correctly and maintain the correct answer. It is usually earlier than the recognition point. Both can be obtained using a gating paradigm that reveals the signal bit by bit (Grosjean, 1980). The N400 effect to isolated single words is indeed affected by the recognition point (O'Rourke & Holcomb, 2002). However, in a more recent study using congruent and anomalous sentences (van den Brink, Brown, & Hagoort, 2006), the isolation point had no effect on the N400 suggesting that the recognition point and the isolation point may be useful indexes only when there is no context to aid the language comprehension.

Although isolation point seems to influence the N400 only in isolated words, target word length has been reported to have robust effects in sentence contexts. In a study by Mäkelä, Mäkinen, Nikkilä, Ilmoniemi, and Tiitinen (2001), very short words (300 ms) resulted in a very sharp N400 when compared with the N400 to words that varied in length (mean 757 ms). In their study, difference could not be explained by the acoustic properties because there was no N400 difference between long and short words in the control subjects who did not understand the Finnish sentences. Even long compound words do elicit the N400 but the latency and the amplitude are different from shorter words (Pratarelli, 1995). These studies did not report the isolation or recognition points. Anyhow, these findings imply that the word lengths in different conditions must be controlled in order to avoid confounding word length effects.

The earlier onset of N400 to speech than to written input may be caused by separate ERP components. A component labeled ‘N200’ or ‘N250’ with N400-like distribution has been suggested to reflect lexical selection processes occurring in speech comprehension prior to semantic integration (Hagoort & Brown, 2000; van den Brink, Brown, & Hagoort, 2001; van den Brink & Hagoort, 2004). The N200/250 is argued to reflect the semantic goodness-of-fit between the lexical candidates activated by the incoming speech signal and the semantic constraints of the context. Connolly and Phillips (1994) identified a negative ERP component peaking between 270 and 300 ms in similar experimental conditions and labeled it the phonological mismatch negativity (PMN). They proposed that the PMN reflects mismatch between the initial incoming phonemes and the initial phonemes of the most expected lexical candidate(s) activated by the preceding context.

1.5.2 N400 to pictures

Nigam, Hoffman, and Simons (1992) presented their subjects with sentences one word at a time on a computer screen. The final item (either word or a corresponding line drawing) was as expected or anomalous. They reported a robust N400 effect with both materials and no differences between word and picture conditions. Since their study, other studies have also reported N400 to incongruent pictures presented as final items after sentence context (Federmeier & Kutas, 2001, 2002; Ganis, Kutas, & Sereno, 1996; Wicha, Moreno, & Kutas, 2003). N400 has also been reported to pictures primed by single written words (Hamm, Johnson, & Kirk, 2002; van Schie, Wijers, Kellenbach, & Stowe, 2003), and by different materials such as other pictures (e.g., Holcomb & McPherson, 1994; McPherson & Holcomb, 1999) and odors (Castle, Van Toller, & Milligan, 2000; Grigor, Van Toller, Behan, & Richardson, 1999; Sarfarazi, Cave, Richardson, Behan, & Sedgwick, 1999).

Barret and Rugg (1989) presented their subjects with pairs of famous faces. The subjects' task was to determine whether the faces belonged to the same occupational category (e.g., actor or politician). The non-matching second faces elicited N400. Bobes, Valdes-Sosa, and Olivares (1994) showed their subjects with famous faces with part of the face (e.g., moustache) exchanged with part from another famous face. This too elicited N400. N400 to incongruent faces suggests that making sense of incongruous visual stimuli is similar to making sense of incongruous sentences.

West and Holcomb (2002) showed their subjects cartoon strips captured from cartoon films. In the incongruent situation, the final frame was from a wrong cartoon. The incongruent situation elicited a long-lasting fronto-centrally distributed negativity. In addition to the N400, they identified a right anterior component that peaked around 325 ms. They argued that this 'N300' component is unique to picture processing[1].

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[1] The N300 component preceding the N400 has also been reported in studies using pairs of pictures (Barrett & Rugg, 1990; Holcomb & McPherson, 1994; McPherson & Holcomb, 1999). The N300 has not been observed in the N400 studies using face stimuli. This early negativity to pictures has been suggested to reflect object recognition processes (Doniger et al., 2000; Schendan & Kutas, 2002), possibly at a categorical level (Hamm et al., 2002). The current experiment does not require fast identification of appearing objects, and therefore the N300 is not expected.

1.6 N400 evidence on the situationist models

N400 to words in a semantically coherent sentence declines as a function of the word position (e.g., Kutas, Van Petten, & Besson, 1988; Van Petten & Kutas, 1990), but this decline is not observed when the sentence is preceded by coherent discourse (Van Petten, 1995). Van Petten argued that when there is strong contextual support available right from the start of the sentence, the N400 amplitudes are equally attenuated throughout the sentence. If the single sentences were processed locally, the N400 amplitude decline should also be observed in single sentences regardless of the supporting discourse context.

St George, Mannes and Hoffman (1994, 1997) were first to show that N400 is sensitive to global-level coherency. N400 to written paragraphs is attenuated if the paragraphs are preceded by a title that expresses the global topic (1994), or, if the discourse structure of the paragraphs makes the final sentence a pragmatically sensible continuation (1997). St George et al. (1997) reasoned that N400 reflects difficulty of integration at both local and global levels.

Van Berkum et al. (1999) showed their subjects semantically coherent written sentences one word at a time, preceded by short spoken contexts. The spoken context either supported or did not support the critical word in the written target sentence. The discourse-incongruent words elicited a larger N400 than the congruent words. This was also observed in a subsequent study in which also the target sentences were spoken (Van Berkum, et al., 2003). The auditory discourse N400 was similar in time-course and topography to the control N400 which was obtained using semantically anomalous spoken sentences. Also, when presented in isolation, the formerly discourse-incongruent and -congruent sentences did not differ. The discourse N400 was elicited not only by sentence-final words, but also by sentence-medial words. The authors concluded that the incoming words are integrated into the situation model instantly, not after the sentence-level processing.

Recently, Nieuwland and Van Berkum (2006) provided interesting evidence about the priority of discourse over single sentences in the N400. They found that final words in sentences that contain an animacy violation (e.g., "The peanut was *in love"*) elicit smaller N400 effects than normal sentence endings (e.g., "The peanut was *salted"*) when preceded by a fairy tail -like context telling about the life of a peanut. Their study shows that sentence-level semantic violation effects can be overrun by a spoken context of a few sentences (approximating on their paper, the critical words were preceded by 20-30 seconds of the context story). This calls into question whether the local meaning is computed at all. Instead, it has been suggested that the incoming lexical items may directly serve to build the situation model (e.g., Gernsbacher, 1994; Givón, 1992; Perfetti & Britt, 1995).

Coulson, Federmeier, Van Petten, and Kutas (2005) studied how the N400 is affected by the association of a word pair and the congruence of a sentence. Two experiments were run: one probing the association effects of word pairs, and the other probing sentence congruity effects. In both experiments, the words were presented sequentially on a computer screen. The sentences were produced so that the word pairs used in the first experiment were used as the final items of the sentences (e.g., 1: “They were truly stuck, since she didn’t have a *spare* TIRE”, 2: “During the test, Ellen leaned over and borrowed my *spare* PENCIL”, 3: “During the test, Ellen leaned over and borrowed my *spare* TIRE”, 4: “They were truly stuck, since she didn’t have a *spare* PENCIL”). The word association had a minimal effect when inserted in sentences, but the anomalous sentences elicited a strong N400. However, the N400 effect in the word-pairs-only experiment was the same size as the N400 effect in the sentence experiment. This finding was interpreted to mean that some lexical context mechanisms were employed in the processing of word pairs but not in the sentence condition. In line with the situationist models, another interpretation is proposed: the same system was behind the N400 in both experiments, but in the sentence experiment, it was utilized in sentence-level comprehension. This is in line with the discourse psychologists’ assumption that the readers try to achieve the most global level of understanding (e.g., Graesser et al, 1997): focus is kept on discourse rather than sentences, and on sentences rather than words.

1.7 N400 evidence on the unitary semantics

Nonverbal and verbal N400 have been compared using pictures, video, and environmental sounds as the nonverbal stimuli. Some studies have used a simple priming paradigm and some have utilized sentence contexts. Most studies have reported some differences in latency, amplitude, or scalp distribution. The results of these studies are troublesome to interpret in terms of unitary and multiple semantics theories because all of these theories admit that words are slower in activating conceptual knowledge which results in confounding recognition-level effects. Also, the observed differences have not been consistent across studies.

Environmental sounds are processed similarly as verbal materials and have access to the same system as proved by inter-modal priming effects. Many differences have also been reported. In one study (Cummings et al., 2006), pictures (e.g. a rooster) were followed by environmental sounds (e.g. "cock-a-doodle-doo"), or corresponding spoken words (e.g. crowing). N400s to unrelated sounds and words (e.g. barking) did not differ in amplitude but the nonverbal N400 was stronger at two frontal electrodes and peaked 70 ms earlier than the verbal N400. Cummings et al. discussed that the latency difference may arise from differences in semantic processing as well as from the fact that actual environmental sounds are recognized faster than their verbal labels (for a review, see Saygin, Dick, & Bates, 2005). Orgs, Lange, Dombrowski, and Heil (2006) used written words primed by environmental sounds and vice versa. They also observed that the environmental sound N400 had an earlier onset, but in their study, the nonverbal N400 had a more posterior distribution. This distribution discrepancy cannot be explained by differences in spoken and written N400s because written words have been considered to elicit a more posterior N400 distribution than spoken words (e.g., Domalski et al., 1991). Van Petten and Rheinfelder (1995) used a setting similar to that of Orgs et al. (2006), but with spoken words. The nonverbal and verbal N400s did not differ in latency or anteroposterior dimension but the nonverbal N400 was stronger over the left hemisphere. Plante, Petten, and Senkfor (2000) used environmental sounds primed by drawings, and spoken words primed by written words. As in the study by Van Petten and Rheinfelder (1995), the nonverbal N400 was stronger at the left, and there were no differences in the anteroposterior dimension or latencies in the normal population. Interestingly, a college-attending learning disabled group was included. They did not differ from the control group in the nonverbal N400 but showed no significant verbal N400. Planet et al. concluded that it is not clear whether the absence of verbal N400 reflects deficits in verbal semantics or phonological processing. The inconsistencies in the observed differences suggest that they reflect variation of stimulus details rather than differences between verbal and nonverbal processing per se.

Federmeier and Kutas (2001) compared picture processing to prior findings about word processing (Federmeier & Kutas, 1999) at a functional level. They replaced the final words from the prior study with corresponding line drawings and manipulated the amount of contextual restraint (final word cloze probabilities[2]). An increase in contextual restraint affected the amplitude of the N400 differently in the picture study than it had done in the previous study using words. The conclusion of Plante et al. (2000) applies to this result also: it is not clear whether the observed difference reflects differences in semantic or recognition-level processes. The results in the study by Federmeier and Kutas (2001) may be explained by differences in the amount of conceptual information initially activated by words and pictures.

Video films containing unexpected events also produce N400. Özyürek, Willems, Kita, and Hagoort (2007) carried out an experiment that resembles the present one. They manipulated expectancy of auditory sentences (e.g., "He slips on the roof and *rolls down / walks to the other side"*) and expectancy of simultaneously presented videotapes of hand gesturing (e.g., a finger showing a descending rolling gesture, or fingers 'walking' horizontally). The subjects' task was to attend to the stimuli. There were three incongruent conditions: either the sentence, gesture, or both could be unexpected. All incongruent conditions produced N400 that was similar in amplitude, latency and scalp distribution suggesting that there were no differences between verbal and nonverbal semantic processing. The N400 was frontally distributed. Videos of everyday tasks performed with a wrong object (e.g., shaving with a broom; Sitnikova, Kuperberg, & Holcomb, 2003), and videotaped gestures incongruent with a spoken word (Kelly, Ward, Creigh, & Bartolotti, in press) also produce a frontal N400. The frontal distribution of the "video N400" differs from the usual verbal N400 distribution that is centro-parietal and slightly stronger over the right hemisphere (e.g., Kutas et al., 1999). Of course, there is an exception to this, too: a normal widely distributed N400 with a central peak has been reported to videos of persons miming an event that was or was not in a preceding animated film (Wu & Coulson, 2005). These studies show that incongruent video presentation produces functionally similar N400 as anomalous language input. The frontal distribution may reflect flexibility of the system behind the N400. Similar computations may be possible to be run at multiple neural

[2] Cloze probability of a word in a context is the probability that subjects would complete the sentence with that specific word (Kutas & Hillyard, 1984).

locations depending on the focus of attention. For instance, the frontal distribution of the verbal N400 in the study by Özyürek et al. (2007) suggests that the computations reflected by the N400 were performed at the same location for both verbal and nonverbal input.

In priming studies, unidentifiable objects (depicted from a strange angle) have been reported to produce a larger N400 than semantically unrelated objects (Holcomb & McPherson, 1994; McPherson & Holcomb, 1999). This parallels the N400 effect to pseudowords which is also larger than the N400 to unrelated words (Holcomb & Neville, 1990). This similarity does not prove that the processing of pictures and words takes place in one system, but this interpretation is more parsimonious than hypothesis of two separate systems that are similar.

The presence of both differences and similarities in the topographical distributions and time courses of nonlinguistic and linguistic N400s has been interpreted as evidence for the existence of both an amodal semantic system, and a separate system for verbal semantic processing (Kounios & Holcomb, 1994; Kutas & Federmeier, 2000; West & Holcomb, 2002). However, the role of the recognition of items and activation of concepts has not been controlled in the studies reporting these differences. Only in the study by Özyürek et al. (2007), verbal and nonverbal materials were simultaneously presented in all conditions. In their study the verbal N400 did not differ from the nonverbal N400 in latency, amplitude, or distribution.

1.8 Aims of the present study

The present experiment provides evidence on the processing stage where the local and global levels, and verbal and nonverbal input start to interact. The local/verbal level consists of spoken sentences that have either a sensible or anomalous final word. The subjects' task is to decide whether the sentences are congruent with complex pictures presented on a computer screen. This forces them to compare semantic information of both the sentence and the picture (global/nonverbal level). The task does not require subjects to process sentences or pictures in isolation. Sensibility of the sentences and the congruency of the sentence- picture pairs is manipulated so that four conditions are formed (table 1).

Table 1: The experimental conditions and hypotheses about the N400 amplitude

		Picture	
		Congruent	Incongruent
Final word	Sensible	S-C	S-I
	Anomalous	A-C	A-I

Main hypothesis, unitary processing: $S\text{-}C = A\text{-}C < S\text{-}I = A\text{-}I$

Counter hypothesis, independent processing: $S\text{-}C < A\text{-}C \approx S\text{-}I < A\text{-}I$

The present study was designed so that the visual recognition and lexical selection processes are not confounded with higher-level processing: In all conditions, the visual stimuli appeared two seconds before the sentence onset and stayed visible so that the relevant items in the pictures would be recognized by the onset of the critical word. The ERPs were time-locked to continuous speech in all conditions.

The basic presumptions behind the present study are that there is only an amodal semantic system that is reflected by the N400, and that the semantic violations in the sentences are not processed independently of the pictures. ERP differences that have previously been reported between the verbal and nonverbal N400 are supposed to reflect recognition-level processes, and in the present study, to be similar over the conditions. Presumably, it is also possible to direct the amodal semantic system to linguistic or non-linguistic information alone, if the task requires this. In the present study, the task did not require evaluation of verbal input in isolation, and therefore it is hypothesized that the sentence-level violation does not affect the N400. Instead, only the incongruence of the pictures and the sentences is hypothesized to increase the amplitude of N400.

Counter hypotheses are that violations at both local and global levels produce independent congruency effects. If the verbal and nonverbal semantic processing are independent of each other the N400 effects should summate: when the sentence is both anomalous and incongruent the largest N400 is observed. If the local level is processed first independent of the global level, the sentence-level N400 should also have an earlier peak than the global-level N400.

2. Methods

2.1. Subjects

17 subjects (8 women) participated in the experiment and received a reward. Mean ages for male and female subjects were 24.0 (standard deviation 1.8) and 23.6 (3.2), respectively. All subjects gave a written consent and were told they could interrupt the experiment at any point. The subjects reported to be right-handed which was confirmed by the Edinburgh handedness inventory (Oldfield, 1971). Mean right-handedness index was +87.1 (14.6) ranging from +50 to +100. Subjects had normal or corrected to normal vision and normal hearing. None of the subjects had any known neurological injuries.

2.2. Stimuli

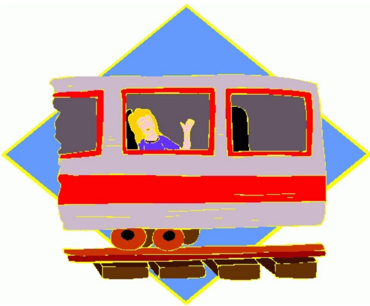
The stimuli were sentence-picture pairs. 62 sentence frames were prepared each with four alternative final words (see appendix A for a list). Two of the final words were sensible, and two anomalous. Each sentence set was composed so that it was possible to produce a matching complex picture for all four sentence variants. The pictures had a general theme that fit the sentence body (for some examples, see table 2).

The pictures were prepared from digital drawings retrieved from free clipart galleries in the Internet. Many of the pictures were manipulated or combined from several drawings or parts of drawings. Resizing and other editing were also used in order to suppress the non-semantic variation of the images. All alphanumeric labels, if present, were removed. All pictures contained several nameable objects or part objects. Paint Shop Pro 9 (www.corel.com) was used to modify the pictures.

2.2.1 Sentences

The sentences were read by the author to a dynamic microphone (RadioShack 33-3018) in a quiet room and recorded with a PC in stereo at a rate of 22000 Hz. Time points of the acoustic onsets of the final words were determined, and the lengths of the sentence frames and the final words were filed using Audacity 1.2.4 audio software (www.audacity.sourceforge.net).

Table 2: Examples of two stimuli from each of the four experimental conditions. (Translations in parentheses and final words in bold.)

Picture	Sentence	Condition
	Ystäväni kulkee yleensä työmatkansa **autolla**. (My friend usually commutes **by car**.)	sensible-congruent
	Ystäväni kulkee yleensä työmatkansa **junalla**. (My friend usually commutes **by train**.)	sensible-incongruent
	Ystäväni kulkee yleensä työmatkansa **junalla**. (My friend usually commutes **by train**.)	sensible-congruent
	Ystäväni kulkee yleensä työmatkansa **autolla**. (My friend usually commutes **by car**.)	sensible-incongruent
	Ystäväni kulkee yleensä työmatkansa **sukeltaen**. (My friend usually commutes **by diving**.)	anomalous-congruent
	Ystäväni kulkee yleensä työmatkansa **aasilla**. (My friend usually commutes **on a donkey**.)	anomalous-incongruent
	Ystäväni kulkee yleensä työmatkansa **aasilla**. (My friend usually commutes **on a donkey**.)	anomalous-congruent
	Ystäväni kulkee yleensä työmatkansa **sukeltaen**. (My friend usually commutes **by diving**.)	anomalous-incongruent

The sentences were not read totally neutrally. Intonation and emotional tone were allowed to slightly fit the theme of the sentence frame. This was hypothesized to make the combined narrative richer and enhance forming of an integrative mental model. This probably increased the overall complexity of the task, which was thought to make the setting more ecologically valid and less monotonous to the subjects.

The sentence frames varied in word count and duration in order to prevent subjects from adopting a strategy of only listening to the final word. Average sentence frame duration was 2.00 (.39) seconds ranging from 1.19 to 2.91 seconds. The sentence frames were read on a speed of approximately two words per second. Average final word duration was 0.69 (.14) seconds, ranging from 0.44 to 1.07 seconds. Sensible and anomalous sentences were similar in descriptive statistics (see appendix B for details).

The final words were verbs, nouns, or adjectives. The relative frequencies of the final words were tentatively studied by searching the basic (dictionary) form of each final word from web pages situated in Finland. Comparison of logarithmic transformations of the number of hits did not reveal statistically significant difference between final words of the sensible and anomalous sentences.

Sensibility ratings, cloze probabilities (CP) of the isolated sentences, and cloze probabilities with the pictures were examined. Total of 21 males (mean age 24.2 (2.8)) and 16 females (23.1 (3.0)) replied to control questionnaires.

The sensibility ratings were attained with reply forms (one in the appendix C). The subjects were prompted to choose whether the sentences seemed predominantly sensible or anomalous to them, or when necessary, “Do not know” (.0077 of the answers). The sensible sentences were evaluated sensible on .89 (.16) and the anomalous sentences anomalous on .92 (.15) of the occasions.

For the cloze probability ratings with pictures, the subjects were asked to produce final words that made the sentences congruent with the pictures. They were permitted to report one to three alternative final words (on average, 1.23 (1.2) answers were provided per sentence). Answers were evaluated correct if any of the alternative words begun with the correct word. Example 1: when the correct word was ‘ydinohjus’ (nuclear missile) the answer ‘ohjus’ (missile) was incorrect. Example 2: if the correct word was ‘rahat’ (money) the answer ‘rahatukkoja’ (money stacks) was accepted. CP for the sensible-congruent condition was .59 (.39), and for the anomalous-congruent condition .50 (.37). None of the final words provided by the control subjects matched the incongruent final word.

CPs for sentences in isolation were collected with a paper form (appendix E). The subjects were asked to report the first and the second word that came to their mind. Two alternative final words were required from the subjects in order to enable the CP to vary between zero and one. With two sensible and anomalous sentence variants the CP would otherwise have varied between zero and half. The average CP of the sensible sentences was .21 (.25). All anomalous sentences had a zero CP, but also .39 of the sensible sentences had a zero CP.

2.3. Procedure

Four conditions were composed from the stimuli: The s*ensible-congruent* (S-C) condition consisted of pairs of sensible sentences and the corresponding pictures. The *anomalous-congruent* (A-C) condition consisted of pairs of anomalous sentences and the corresponding pictures. In the *sensible-incongruent* (S-I) and the *anomalous-incongruent* (A-I) condition, the sentences were paired with wrong pictures. For each subject and each sentence set, either the sensible or the anomalous pictures were switched into incongruent. This was randomized. A total of 496 different sentence-picture pairs were possible (62 sentence frames × 4 final words × 2 congruences).

Sentences were presented through professional headphones (Sony Dynamic Stereo Headphones, MDR-7506) at a comfortable level chosen by the subjects. Incidentally, all subjects were satisfied with the starting level. The average peak sound pressure at the distance of the ear was 62.4 (1.7) dB during the sensible sentences, and 62.2 (1.6) dB during the anomalous sentences. The pictures were presented at a 17 inch LCD computer screen (Hercules Prophetview 920DVi) which was placed approximately 120 centimeters in front of the subject. The resolution was 1024 × 768, the refresh rate 60 Hz, and the color depth 32 bits. The mean visual angles were 8.05° (1.7) and 7.87° (1.42) in horizontal and vertical directions, respectively. The average horizontal visual angle of the anomalous pictures was slightly larger [mean difference 0.52°, $t(246)=2.293$, $p=.023$].

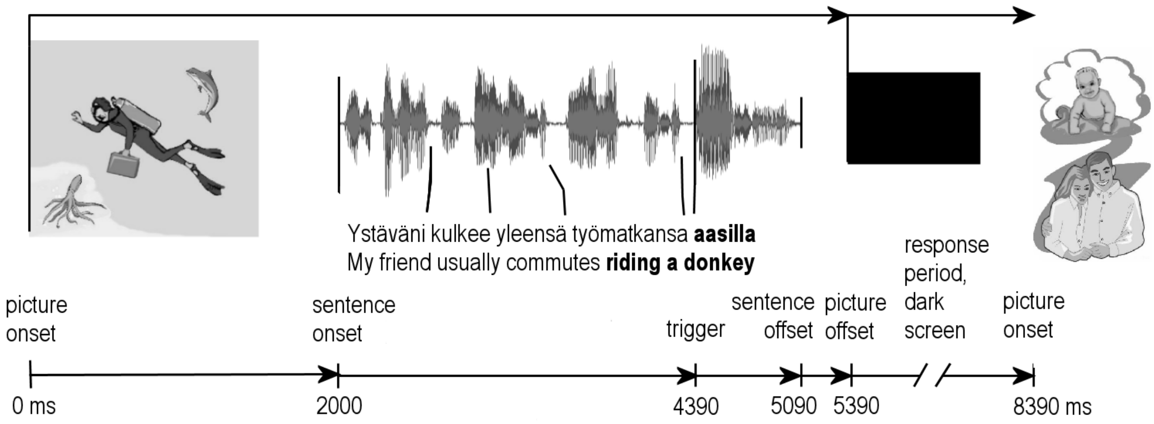


Figure 5: Example stimulus course (Anomalous-Incongruent)

The time course of a stimulus is presented in figure 5. The picture became visible two seconds before the onset of the sentence and disappeared one second after the onset of the final word (with the exception of the longest final words for which the offset of the picture was set to a minimum of 100 ms after the offset of the word). The screen remained dark for three seconds before the onset of the next picture.

The order of the stimuli was pseudo-randomized separately for each subject. Between stimuli with the same sentence frame there had to be at least three stimuli with a different sentence frame, and no more than four incongruent or congruent stimuli were allowed in a row. The 248 stimuli were divided into three blocks. A practice round with one unused stimulus from each condition was run before the EEG recording began.

The subjects received a written instruction (appendix F) for the experiment during preparation of the EEG recording. The task was to assess the compatibility of the picture and the sentence. The responses were delivered with a computer mouse using thumbs. For half of the subjects, the right button was ‘correct’ and the left button ‘incorrect’. For half of the subjects, the assignment was reversed. The responses were to be delivered during a three-second inter-stimulus interval, not before the picture was withdrawn. If the subjects were not fast enough in their response, they were told not to worry but to concentrate on the new incoming stimulus. They were informed about the sensitivity of EEG to muscular activity and instructed to blink only during the inter-stimulus interval and at the beginnings of the sentences, if possible.

2.4. EEG recording and analysis

EEG were recorded from 64 scalp locations using 64 location electrode caps (BioSemi, Inc.). Electrodes were also placed at the mastoids, above and below the right eye, and at both outer canthi. The electrode locations in the caps correspond to the international 10/20 system. EEG recording took place in an acoustically and electrically shielded room with BioSemi ActiveTwo system using active Ag-AgCl -electrodes. Electrode offsets were kept below 25 μV. The digitization rate was 512 Hz.

Data were offline re-sampled to 300 Hz, referenced to the average of the two mastoids, and first filtered to 1 – 50 Hz (until after the artifact removal). EEGLAB toolbox (Free Software Foundation inc.; for a presentation, see Delorme & Makeig, 2004) for MATLAB (Mathwork inc.), and FastICA algorithm (Hyvärinen, 1999) were used for analyses and artifact correction. Data were corrected for eye blinks and horizontal saccades using independent component analysis (ICA) which has been shown to be effective in detecting artificial components in the EEG (Jung et al., 2000). Unepoched EEG was first pruned for irregular artifacts and then decomposed. One horizontal and one vertical ocular component were removed (in most cases, blinking and horizontal eye movements loaded on two stereotypical components). They were manually identified on the basis of topographical and temporal power distributions. After the ocular artifact correction, the EEG was low-pass filtered to 30 Hz. Epochs ranging from 100 ms pre stimulus to 1000 ms post stimulus were extracted and baseline corrected using the pre-stimulus period. 89 % of the epochs were retained after rejecting epochs that contained voltage drifting more than ± 50 μV.

2.5. Statistical analyses

The EEG data were factorized topographically by fitting a symmetrical grid of nine compartments over 61 scalp electrodes (fig. 6). Electrodes P9, P10, and lz were excluded from the statistical analyses. The three levels of the anteroposterior factor were labeled frontal, central, and parietal, and the three levels of the lateral factor were labeled left, medial, and right. ERPs were averaged for each condition. Grand average ERPs (fig. 8) and topographical voltage maps (fig. 9) were calculated.

Peak amplitude latencies were determined at the electrode Pz in a time window from 250 to 600 ms. N400 mean amplitudes for statistical testing were calculated for all conditions in ± 75ms time-windows surrounding the N400 grand average peak latencies. Differences in the N400 amplitudes were tested in a full factorial repeated measures analysis of variance (ANOVA). The main effects of the congruency and the sensibility were tested using paired samples t-tests on the data collapsed over sensibility and congruence (using ANOVA contrasts with a pooled error term is generally not recommended in a repeated measures design (Howell, 2002)). Also, differences between the four conditions in the N400 latencies, reaction times, and the proportion of correct responses were tested.

All p-values for comparisons with more than one degree of freedom were corrected for sphericity violations. A modification to the conservative Greenhouse-Geisser correction has been proposed when the true epsilon is assumed to be 0.75 or above (Huynh & Feldt, 1976). Accordingly, the Huynh-Feldt correction was used when the Huynh-Feldt's epsilon was greater than 0.75, and when it fell below 0.75, the Greenhouse-Geisser's epsilon was applied. All other analyses on the ERPs are post-hoc analyses done on the basis of inspections of the figures 8 and 9, and will be introduced within the results. Significance level corrections are not computed for the post-hoc tests because they are interpreted tentatively.

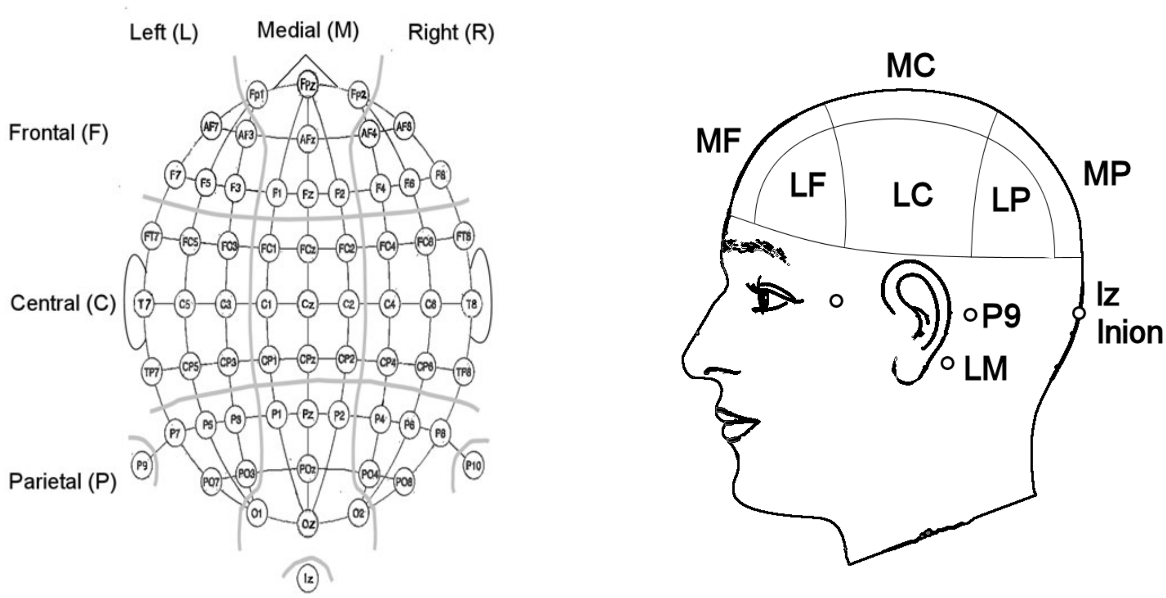


Figure 6: Electrode grid, the anteroposterior and lateral factors, and left side view of the cells

3. Results

3.1 Behavioral data

The condition had no overall effect on the reaction times [F(3,48)=1.938, p=.169]. Either the decision process was equally demanding in all conditions, or the easiness of the task caused a ceiling effect (the subjects were asked to delay their responses until the offset of the picture). The condition had a significant overall effect on the proportion of correct responses [F(3,48)=6.102, p=.004]. The responses in the A-I condition were most accurate, but generally, the responses were very accurate in all conditions. Behavioral data are illustrated in figure 7.

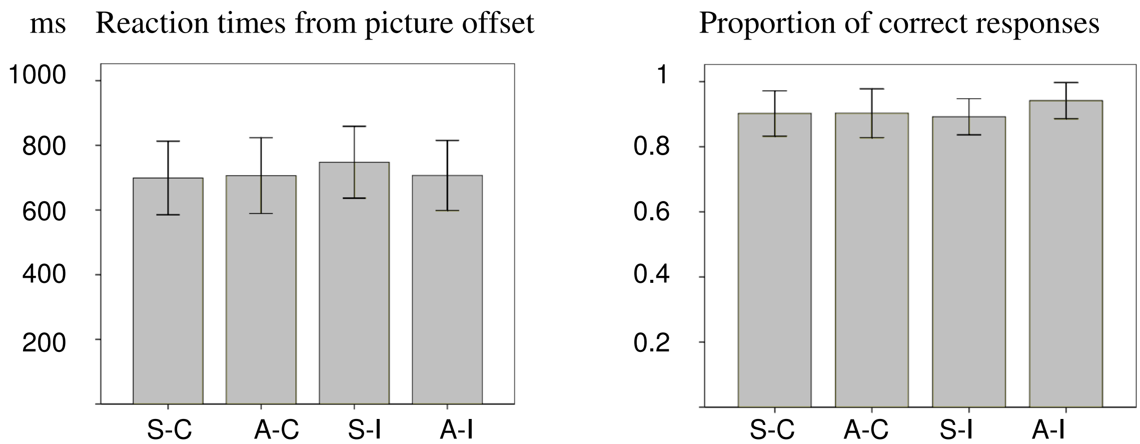


Figure 7: The behavioral data (.95 error bars)

3.2 ERP data

The ERPs in the congruent conditions differed minimally (see figure 8), as hypothesized. Both incongruent conditions produced a large centro-parietally distributed negativity in the N400 window as hypothesized. The N400 in the A-I condition rose and declined later than the N400 in the S-I condition.

The voltage-map data in the figure 9 also suggest that there was a latency difference between the S-I and the A-I conditions. The N400s in the S-I and A-I conditions had similar topographical distributions. The negativities in the incongruent conditions were centro-parietally distributed and slightly stronger over the right hemisphere. There were also left anterior positivities that might reflect the positive ends of the same dipoles.

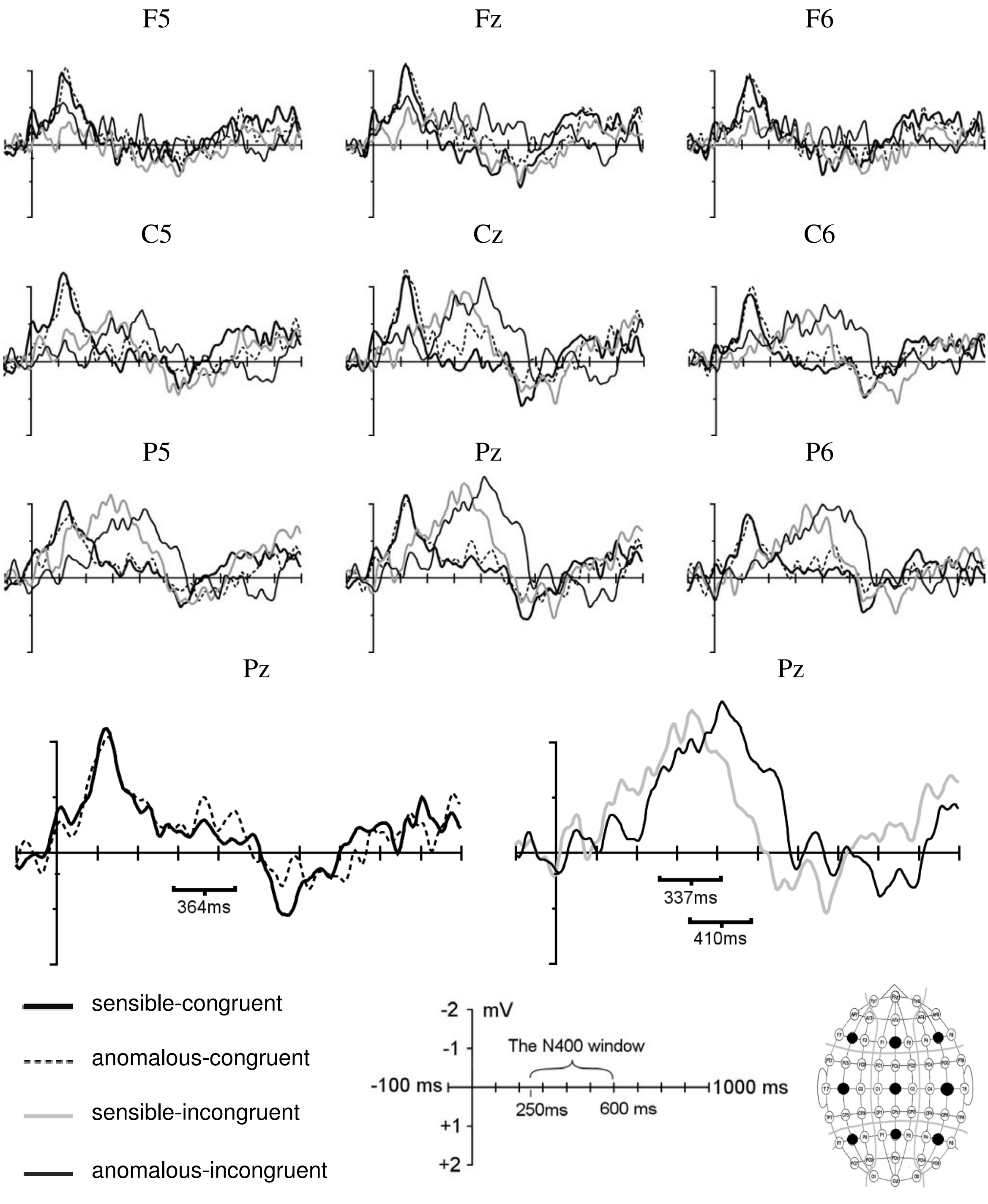


Figure 8: Grand average ERPs of the four conditions at nine electrode locations, and the intervals for statistical testing surrounding the N400 peak latencies.

There were also early differences between congruent and incongruent conditions before the N400 time window (figs 8 & 9). The early negativities seem to have a smaller amplitude in the incongruent conditions and the early negativity in the anomalous-incongruent condition had an atypical, frontal distribution.

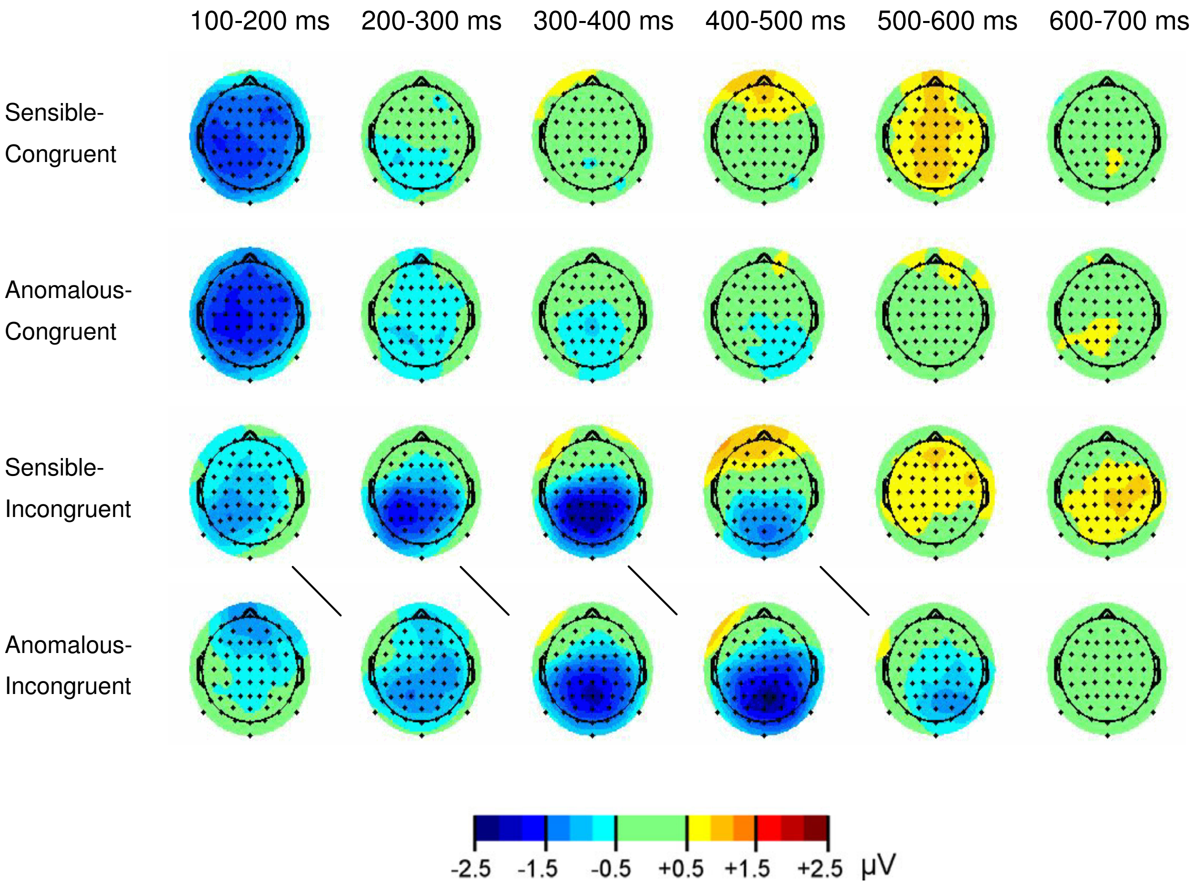
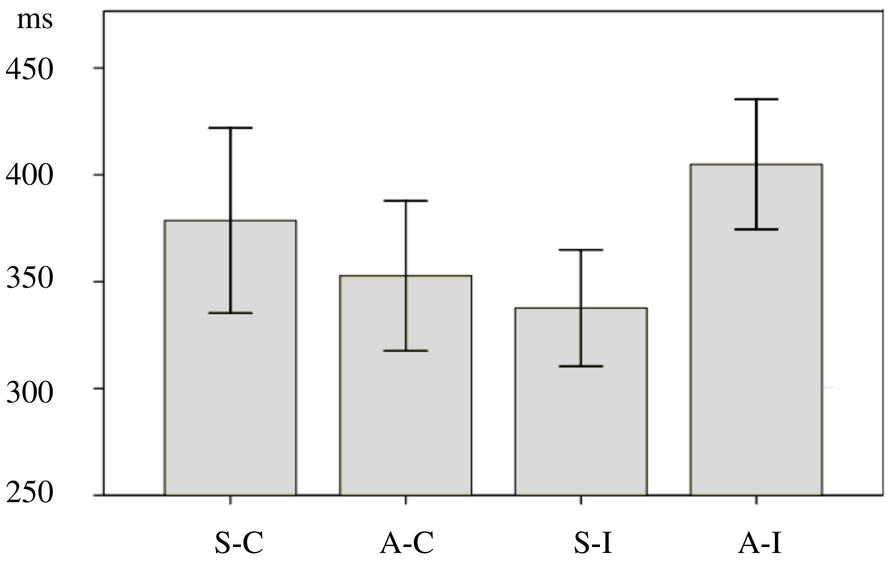


Figure 9: Averaged voltage maps of the four conditions in consecutive 100 ms time-windows. The 'skirts' outside the head depict the most ventral electrode locations that in a spherical model would be invisible from the top view.

3.2.1 N400

The condition had a significant overall effect on the N400 peak latencies [F(3, 48)=3.431, p=.024] (fig 10). In post hoc pairwise tests, only the S-I and A-I differed [mean difference 67ms, t(16)=3.133, p=.006]. The peak latency means were close to the grand average peak latencies around which the N400 amplitudes were calculated.

The full factorial repeated measures ANOVA on the N400 mean amplitudes (see fig. 7 for the time-windows) revealed significant main effect of the condition, and significant interactions condition $\times$ anteroposterior, condition $\times$ lateral, and condition $\times$ anteroposterior $\times$ lateral (table 3). The variance of the condition factor is largest at the medial parietal electrode locations (MP) which was used as the representative cell in the subsequent analyses.

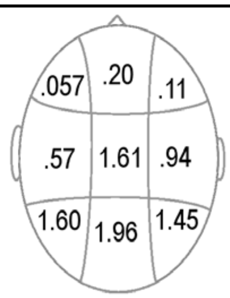


	S-C	A-C	S-I	A-I	
N400 peak latency mean	379 (84)	353 (68)	338 (53)	405 (59)	ms
N400 grand average peak latency	364	364	337	410	ms

Figure 10: Average N400 peak latencies of the different conditions at the Pz (.95 error bars).

The results at the MP are as hypothesized: the N400 is significantly larger in the incongruent conditions, and the sensibility of the sentences had no significant effect on the N400 (table 4). The order of the mean amplitudes (fig. 11) is partially in line with the counter hypothesis (N400 is smallest in the S-C condition and largest in the A-I condition). However, the counter-hypothesized differences S-C < A-C, and S-I < A-I are not significant in pairwise comparisons, and the N400 amplitude in A-C does not roughly correspond to the N400 amplitude in the S-I.

Table 3: Results of the full factorial ANOVA on the N400 amplitudes and cell variances of the condition factor in the N400 window

Comparison	Test	Significance	Cell variances
Co	$F(3, 48)=5.302$	.006	
Co × Ap	$F(6, 96)=7.055$	<.001	
Co × La	$F(6, 96)=3.383$	.011	
Co × Ap × La	$F(12, 192)=2.841$	.003	

Condition factor = Co, Anteroposterior factor = Ap, Lateral factor = La

Table 4: Results of the N400 amplitude comparisons at the middle-parietal cell. Upper: ANOVA on the condition effects. Lower: paired samples t-tests on the data collapsed over congruence and sensibility

Sensible-Congruent	Anomalous-Congruent	Sensible-Incongruent	Anomalous-Incongruent	Test	Significance
-0.32 (.73)	-0.51 (.90)	-1.72 (1.34)	-1.88 (.96)	F(3, 48)=14.15	<.001
Congruent		Incongruent			
-.42 (.68)		-1.80 (.98)		t(16)=5.290	<.001
Sensible		Anomalous			
-1.02 (.82)		-1.20 (.73)		t(16)=.858	.404

Mean in μV, standard deviations in parentheses

The sentence-level effect was tentatively examined at the middle-central cell where the S-C and A-C seem to differ slightly (the significance levels are somewhat meaningless in comparisons of most apparent post-hoc observed differences (Howell, 2002)). The sensibility had no significant overall effect [t(16)=1.261, p=.225], and the post-hoc comparison between the S-C and A-C also fails to reach statistical significance [mean difference 0.53 μV, t(16)=1.910, p=.074].

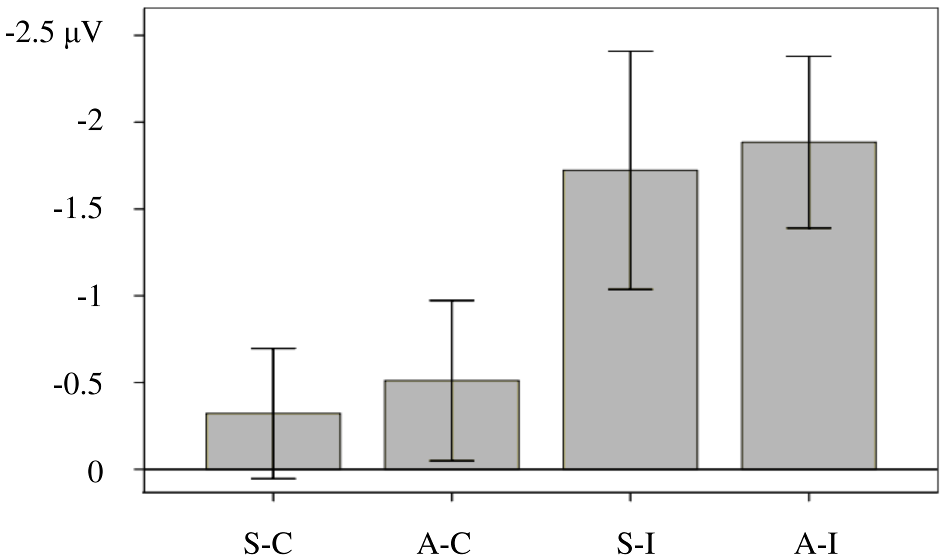


Figure 11: N400 average amplitudes at the middle parietal cell (.95 error bars)

3.2.2 Early differences

The early ERPs (tested between 100 ms and 150 ms) differed significantly between the four conditions [F(3,48)=8.891, p<.001] (fig. 11). The congruent conditions were more negative [difference 1.04 µV, $t(16)=3.782$, $p=.002$]. The main effect of sensibility was not significant. Topographical differences were tentatively inspected in multiple factorial ANOVAs. S-C, A-C, and S-I do not differ from each other, but A-I distribution differs from the other conditions. A-I is stronger at the anterior locations, and the rest at the central locations [$F(2, 32)=11.085$, $p=.003$]. S-C, A-C, and S-I are also slightly stronger over the left hemisphere, although this effect is not significant [$F(2,32)=3.063$, $p=.061$].

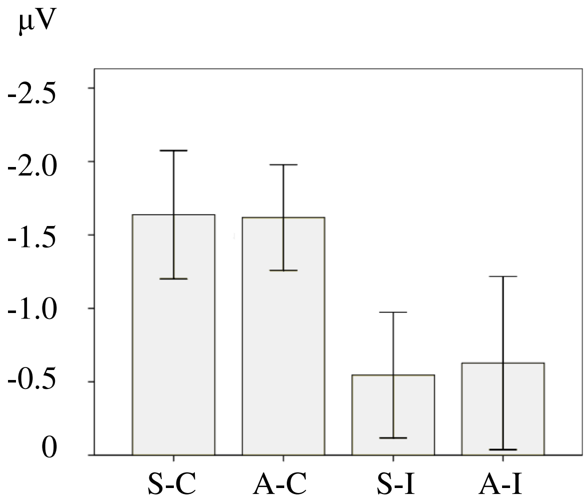


Figure 11: Average amplitudes in the early time window 100-150 ms across all electrodes (.95 error bars).

4 Discussion

The present experiment was designed to compare verbal and amodal semantic processing, and local and global semantic processing using the ERP technique. The focus was on the N400 brain response that reflects semantic integration and is larger to items that do not fit the preceding context. The study combined linguistic and pictorial expectancy violations and kept the perceptual demands equal across the conditions. Results revealed a robust N400 brain response to amodal global-level incongruence. Sentence-level anomaly did not influence the N400 amplitude but did cause a latency shift to the N400 when the incongruent sentence-picture pairs were also anomalous. The results are as hypothesized on the basis of unitary semantics theories and situationist theories of language comprehension.

4.1 Local- and global-level effects

Sentence-level anomaly did not influence the N400 amplitude suggesting that there was no independent processing of the sentences. The N400 in the A-I condition was, however, delayed in comparison to the S-I condition. This might be understood in terms of the two-step models of language comprehension: an attempt to comprehend the sentence-level violation delayed the integration to the global level. This interpretation implies that the processing of the sentence-level violation took place at such a level that does not produce N400, because the A-C and S-C do not differ. Another interpretation is that the word recognition in the A-I was more dependent on the bottom-up information than in the S-I. Anomalous materials may pre-activate a smaller cohort of lexical units. Sensible discourse pre-activates a larger cohort of lexical units that are can be expected in the ongoing discourse. Word recognition is flexibly both bottom-up and top-down driven (e.g., Elman & McClelland, 1984). In the A-I condition, the recognition was more dependent on bottom-up information, and more of the auditory stream had to be heard before the incongruence was confirmed.

A 'semantic illusion' (Erickson & Mattson, 1981; for reviews, see Ferreira, Ferraro, & Bailey, 2002; Sanford & Sturt, 2002) could be proposed to explain the absence of the sentence level N400 effect. In a semantic illusion, subjects are blind to the anomalousness of the discourse and somehow assume a default interpretation that makes sense (e.g., "No head injury is too trivial to be ignored" is understood as "head injuries *should not* be ignored", although the sentence actually claims the opposite). The semantic illusion is an improbable explanation for absence of the sentence level N400 given that the control subjects evaluated the anomalous sentences anomalous on 92% of the occasions and the subjects in the experiment detected the incongruence on 91% of the occasions. A semantic illusion, if present, should have been evident also in the behavioral data.

The present experiment does not prove whether there is *any* semantic processing at the local level prior to the global-level processing. The scope was in the system(s) reflected by the N400. It could be argued that the local semantic meanings of the sentences were computed in a system whose functioning is not manifested in the ERPs. Although interesting, this seems difficult to falsify experimentally.

4.2 Unitary versus multiple semantics

The dual-coding hypothesis asserts that the verbal and the nonverbal systems function independently (Paivio, 1986). The present findings suggest that the verbal input was not processed independently because the sentence-level anomaly did not influence the N400 amplitude. A more complex multiple semantics model could account for the present findings, and the fact that N400 has been reported using verbal, non-verbal, and multimodal stimuli. There could be three semantic systems that are all able elicit N400: verbal, non-verbal, and a flexible amodal system. It could be argued that the verbal system only functions intentionally if the task requires processing the sensibility of the language input.

However, the auditory N400 does not require intentional processing of meanings. Connolly, Stewart, and Phillips (1990) studied how the subjects' task influences N400 to anomalous final words in spoken sentences. Passive listening condition, letter search, sound search, and semantic category judgment task all produced similar N400. N400 to auditory word pairs has even been observed during sleep (Brualla, Romero, Serrano, & Valdizan, 1998; Perrin, Bastuji, & Garcia-Larrea, 2002). On the other hand, the N400 to auditory word pairs can be attenuated with a non-semantic distracter task (Bentin, Kutas, & Hillyard, 1993; Hohlfeld & Sommer, 2005; Perrin & Garcia-Larrea, 2003). Hohlfeld and Sommer (2005) were able to completely eradicate the N400 with a taxing dual task. Relander (2006) nearly eradicated the N400 with a video learning task. In summary, there is evidence that auditory N400 is prone to task related attenuation when using word pairs, but these findings haven't been generalized to sentence contexts.

In the present study, there was no distracter task and the task was generally rather easy. There is no reason why the verbal system would not be operational if it is independent, the task is rather easy, and attention is directed also to the sentences. If the independence principle is discarded, many findings could be explained by claiming that the verbal semantic system does not function if the amodal semantic system is better suited for the task. This kind of interpretation is difficult to falsify. A more parsimonious interpretation is that there is only the flexible amodal system that can process verbal and nonverbal input in parallel, and when necessary, separately.

Most previous N400 studies that contrasted verbal and nonverbal processing using environmental sounds or pictures have reported differences in scalp distributions. The dissimilar distributions have been interpreted in favor of the multiple semantics theories (e.g., Holcomb et al., 1999). The previous studies presented the critical items sequentially with empty interstimulus intervals, often with a verbal prime and a nonverbal target or vice versa. This makes it impossible to separate deeper processing effects from effects that reflect recognition of items and activation of concepts. As argued by Caramazza et al. (1990), the distinction between unitary and multiple semantics should go beyond the level of recognition and activation. In the present study, the perceptual requirements were kept similar in all conditions by recording ERPs to continuous speech and providing the visual context well before the critical word onset. The N400 scalp distributions were very similar in the S-I and the A-I conditions.

4.3 Early effects

Differences in the N100 time window (100-150 ms) cannot be explained by differences in the timelocking or phonetic differences between the congruent and the incongruent conditions because the sentences were the same – only the pictures were switched. Some differences in the timelocking and phonetic qualities are possible between the anomalous and sensible sentences, but their influence does not seem likely because the early ERP effects are almost identical in the congruent conditions and similar in the incongruent conditions. Because the sentences consisted of continuous speech, it is possible that the early effect is time-locked to some phonemic variation prior to the final word onset. The early negativity could be an ERP effect that is usually reported around 200 ms post stimulus onset.

Negative ERP effect around 200 ms is common in auditory target detection. The subjects may have considered incongruence as the default and tried to detect congruent stimuli. It is not probable that this was aided by a strong lexical expectation because the incongruent stimuli did not elicit N200 or PMN that reflect lexical and phonetic expectancy violations.

Another possibility is that the early negativity is a visual ERP reflecting attention shift to the relevant aspect or object in the picture. It could also reflect visual recognition if the object indicated by the final word is not kept active in the working memory. Incongruent conditions might have failed to elicit this, because the final words did not refer to any features in the pictures.

4.4 General discussion

Caramazza (1996) has proposed that all meaning-level information is mainly processed in the left hemisphere. This view has received support from two PET studies (Bright et al., 2004; Vandenberghe et al., 1996), and one fMRI study (Postler et al., 2003) that compared semantic processing of pictures and words (subjects evaluated semantic relatedness of word or picture pairs). These studies identified activation patterns common to picture and word processing and unique activation patterns. All studies reported common semantic activation in the left inferior frontal gyrus and left middle temporal gyrus. In addition, the two PET studies reported common activation around left temporal-occipital-parietal junction and around left ventral temporal cortex. Processing of pictures elicited unique activation at posterior areas in the fusiform gyrus, occipital, and parietal cortices. More activation zones were reported in the left hemisphere. It has been suggested on the basis of brain-damaged patient studies that verbal semantics is represented only in the left hemisphere but visual semantics in both (Coslett & Saffran, 1989). The findings of these brain imaging studies suggest the opposite. Temporal and frontal activation unique to picture processing was detected almost solely in the left hemisphere, but word processing activated areas bilaterally. Only the fMRI study by Postler et al. (2003) reported any picture related activation in the right temporal or frontal cortex (specifically, in the right middle frontal gyrus).

Semantic processing of environmental sounds has also been associated with the same cortical regions as semantic processing of language. In one PET study, listening to meaningful sounds, in contrast to meaningless sounds, was specifically associated with activation of the left superior temporal gyrus, the left parahippocampal gyrus, and the left inferior frontal gyrus (Engelien et al., 2006). Semantic processing in the language domain is also most strongly associated with activation of the left superior temporal gyrus and the left inferior frontal gyrus (for reviews, see: Bookheimer, 2002; Van Petten & Luka, 2006). Also, a study on the left hemisphere-damaged aphasic patients' comprehension of matched verbal and environmental sound stimuli demonstrated that deficits in these two domains are highly correlated (Saygin, Dick, Wilson, Dronkers, & Bates, 2003).

It has been suggested in language research, that although the semantic memory is distributed diffusely in the cortex, semantic processing is coordinated and bound together by an executive system in the left lateral prefrontal cortex and possibly in the left anterior temporal cortex (Bookheimer, 2002; Martin & Chao, 2001). The verbal N400 is most strongly associated with the superior temporal gyrus and somewhat inconsitently with the inferior frontal gyrus (Van Petten & Luka, 2006). It seems most likely that these areas coordinate also non-verbal semantic processing. In addition to the data from localization studies on non-verbal semantic processing, N400 studies also support this conclusion: a consistent finding has been that a non-verbal prime amplifies the N400 to unrelated words and vice versa (e.g., Kutas & Federmeier, 2000).

Semantic processing of pictures and written words has produced different activation patterns mostly at posterior cortical locations (Bright et al., 2004; Postler et al., 2003; Vandenberghe et al., 1996), not at the temporal and prefrontal areas that are hypothesized to coordinate the semantic processing. Activation at the parietal, occipital and posterior temporal cortices has been suggested to reflect pre-semantic processing (Bright et al., 2004)[3]. In this view, modality specific effects can be seen to reflect modality specific advantage in accessing certain sensorimotor attribute domains in the semantic memory (Thompson-Schill et al., 2006). For instance, people are faster at making action decisions (e.g., pour or twist?) about picture stimuli than word stimuli (Chainay & Humphreys, 2002). The differences in scalp distributions reported in most studies comparing N400 to different stimulus materials (e.g., pictures, written words, spoken words, videos, and environmental sounds) may well reflect different memory access requirements of the materials used, rather than differences in semantic processing.

4.5 Restrictions of the present study and future areas of interest

The present sentences were only presented in picture context and purely verbal ERPs were not recorded. If the verbal ERPs had been available, it would have been possible to see how the picture context generally affected the ERPs. For instance, would the early ERP

[3] Bright, et al. (2004) did not elaborate on the distinction between semantic and pre-semantic processing. In the present paper, activation and access of concepts in the semantic memory is considered pre-semantic processing. Integrating, comparing, and executive control of retrieval are counted as semantic processing.

effects be similar and would the verbal N400 to the anomalous sentences have a similar time course as the amodal N400 in the present experiment? The possibility that the verbal ERPs between the sensible and anomalous sentences would not differ is highly unlikely given the robustness of the N400 effect and the high agreement on the sensibility and anomalousness of the sentences.

It is possible that functional differences between anomalous and sensible stimuli exist that do not manifest in the scalp recorded N400 effect. For instance, Hagoort, Hald, Bastiaansen, and Petersson (2004) reported similar ERP and fMRI findings both to semantic and world knowledge violations in their sentences, but the time-frequency representations of the ERPs revealed differences. One future direction would be to use materials similar to the present study in a hemodynamic localization study or a wavelet based ERP study.

The present study did not involve manipulation of the task. The hypothesis that one system behind the N400 can be utilized in processing of association of pairs of stimulus, multimodal associations, or congruency of large contexts can be tested more specifically. It could be examined how the N400 is affected if the subjects concentrate on a certain semantic level (e.g. if the task is to judge the sentence level sensibility regardless of the pictures, which are randomized over the sentences). Thus far, only N400 studies that have contrasted semantic and non-semantic tasks have been reported. Also, a passive attending task would be informative as it would eliminate the possibility that the subjects only concentrate on the final word of the sentence.

4.6 Conclusions

Most N400 studies that have compared verbal and nonverbal semantic processing have found similar N400 amplitude effects for both materials although differences in scalp distributions have been reported. In hemodynamic localization studies, semantic processing areas have been identified that are common for processing of pictures and words. Activation areas unique to picture processing have been posterior suggesting pre-semantic processing. ERP and hemodynamic studies so far have not controlled the influence of the pre-semantic processing (with the exception of the study by Özyürek et al., 2007). The present findings further support unitary semantic theories by showing that when the pre-semantic processes are controlled and the task requires simultaneous processing of pictorial and verbal input, no differences between verbal and amodal processing are detected. It is very unlikely that the semantic meanings of the sentences were locally computed because the sentence-level anomaly did not influence the N400 amplitude. There is a growing body of evidence indicating that the verbally and nonverbally provided semantic information are processed in a unitary system, and the local meaning of a clause is not computed before contextual integration.

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Appendices

Appendix A: The sentences (the last two words anomalous)

1. Jo dinosaurukset osasivat lentää / sukeltaa / rakastaa / musisoida
2. Annoin vanhat aurinkolasini yhdelle miehelle / naiselle / pingviinille / jääkarhulle
3. Töissä käyttämäni tietokone on kannettava / vanhentunut / rakastunut / sairastunut
4. Pidän käsilaukussani yleensä meikkiä / kukkaroa / kukkoa / kaulinta
5. Jäätiköllä vaeltaessamme törmäsimme jääkarhuun / pingviiniin / budhaan / ritariin
6. Karateohjaajana toimi eräs nainen / japanilainen / simpanssi / tonttu
7. Mies on heittämässä keihästä / tikkaa / kettua / kynää
8. Joidenkin poliisien henkilökohtainen ase on pistooli / pamppu / banaani / kynä
9. Lapseni kulkee kouluun bussilla / kävellen / raketilla / tankilla
10. Kimmo piirsi koulussa kuvan itsestään / seeprasta / kuolemasta / shamppanjasta
11. Oppiakseni puolustautumaan aloin harrastaa judoa / nyrkkeilyä / shakkia / golfia
12. En haluaisi olla töissä vaan purjehtimassa / rannalla / sodassa / hirtettävänä
13. Kiinalaisessa taiteessa esiintyy usein lohikäärme / tiikeri / meloni / kokki
14. Kaupungin yllä leijui pilvi / ilmalaiva / huulipuna / pitsa
15. Tyypillistä - ruokaani on lennähtänyt kärpänen / lehti / lepakko / kirves
16. Japanilaisessa taiteessa esiintyy usein aallokko / tulivuori / lumimies / mammutti
17. Armeijan uusi suojaväri oli ruskea / vihreä / pinkki / keltainen
18. Ajattelimme lähteä lomalle rannalle / vuorille / avaruuteen / vankilaan
19. Syön nykyään harvemmin lempiruokaani kanaa / pitsaa / lääkkeitä / saippuaa
20. Laitan yleensä leivän päälle makkaraa / juustoa / kukkia / sammakoita
21. Lentotukialuksen kannella on lukuisia hävittäjiä / koptereita / seeproja / linja-autoja
22. Mikko notkui baarissa seuranaan eräs nainen / humalainen / apina / gaselli
23. Ystäväni kulkee yleensä työmatkansa autolla / junalla / aasilla / sukeltaen
24. Hankimme tyttärellemme lemmikiksi kanin / koiran / lehmän / tiikerin
25. Nykyään soitan usein orkesterissa / kitaraa / kengässä / pyöräillessä

26. Eräs tuntemani poliisi syö usein purilaisia / donitsia / kenkiä / kirjaa
27. Sadonkorjuun aikaan poimimme talteen omenat / rypäleet / rahat / pullot
28. Entinen luokkatoverini Maija on nykyään rauhallinen / kiireinen / vamppyyri / enkeli
29. Markku kantaa sylissään kukkia / lasta / sarvikuonoa / autoa
30. Uusi työtoverimme on hyökkäävä / mietiskelevä / ankka / karhu
31. Vangilla on sellissään hiiri / juliste / lumiukko / linnunpesä
32. Annoin rakkaalleni lahjaksi runon / kukkia / nappeja / patterin
33. Olohuonetta piristää kummasti hankkimani maalaus / matto / pönttö / pommi
34. Naapurini sai eilen saaliiksi peuran / kalan / tähden / hevosen
35. Eilen aamulla televisiosta tuli vain joku ooppera / piirretty / hyönteinen / kummitus
36. Kummitätini polttaa joskus kuistillaan kynttilöitä / tupakkaa / porkkanoita / kirjoja
37. Siivotessani löysin sängyn alta kirjan / vaatteita / diplomaatin / kamelin
38. Juulian isä on ammatiltaan tutkija / rakennusmies / shamaani / merirosvo
39. Viimeaikoina olen tavannut herätä pirteänä / väsyneenä / kuolleista / seinältä
40. Perheemme on jo pitkään asunut maalla / kaupungissa / kuussa / puussa
41. Opettaja piti tämän päivän oppitunnin seisaaltaan / istuen / lammessa / helvetissä
42. Kesällä on mukava istua iltaa nuotiolla / terassilla / autossa / luolassa
43. Ajattelin ostaa uuden lampun / sanomalehden / naaman / luurangon
44. Minä ja vaimoni olemme ajatelleet hankkia lapsen / omakotitalon / ydinohjuksen / orjan
45. Olen tottunut käyttämään kirjoja lukemiseen / sisutamiseen / laskuvarjona / tyynynä
46. Rahanhankkimisessa auttaa yleensä työnteko / osakepeli / haavi / pistooli
47. Minusta mukavin kotiaskare on imuroiminen / tiskaaminen / teurastus / kaivaminen
48. Ennen muinoin pitkät matkat taitettiin hevosilla / meritse / matolla / juosten
49. Taloyhtiössämme ramppaa jatkuvasti poliisi / kauppiaita / marssilaisia / vuohia
50. Koiramme ajaa usein takaa kissaa / postiljoonia / meteoriittia / valaita
51. Laitan yleensä kahviini maitoa / sokeria / hiiren / myrkkyä
52. Pienokaisemme oppi kesällä kävelemään / potalle / lentämään / ryyppäämään
53. Pukeudun lomalla yleensä baskeriin / shortseihin / laatikkoon / tynnyriin
54. Myöhästyin koska jäin jumiin hissiin / ruuhkaan / tulppaaniin / faksiin
55. Naapurimme ovat rakentaneet pihalleen uima-altaan / kasvihuoneen / kirkon / tehtaan
56. Setäni kasvattaa maatilallaan maissia / lampaita / kiinalaisia / palmuja
57. Laivamme oli viimeinkin saapumassa avomerelle / satamaan / vuorelle / keittiöön
58. Tänään valmistetaan ruoaksi kalkkunaa / porsasta / käpyjä / hattu
59. Unettomina iltoina alan usein pelata tietokonetta / pasianssia / rugbyä / jääkiekkoa
60. Valtion pitäisi satsata enemmän vanhuksiin / lapsiin / pupuihin / curlingiin
61. Päivän postissa oli laskuja / paketti / koira / kuorma-auto
62. Kotka on saanut saaliikseen rotan / lokin / maapallon / nojatuolin

Appendix B: Sentence descriptives

Sentence and word durations, word counts, letter counts, and log frequencies of the final words

	Sensible	Anomalous
Sentence frame word count	3.87 (.82) [3 – 6]	
Reading durations per word during the sentence frame	522ms (95)	523ms (90)
Sentence frame durations	1986ms (400) [1190 – 2862]	1992ms (385) [1244 – 2908]
Final word letter count	8.19 (2.1) [5 – 13]	8 (2.0) [5 – 12]
Final word durations	694ms (132) [441 – 1039]	692ms (152) [447 – 1070]
Final word log frequencies	5.314 (.826) [2.389 – 7.013]	5.118 (.766) [2.757 – 6.883]

Standard deviations are in parentheses and range in brackets.

Appendix C: Sensibility rating form (1/2)

Tutkimusputkimus

Älä poista kyselykaavakkeen lukitusta, koska silloin vetolaatikot eivät toimi. Vastaile vain vetolaatikoihin ja kun olet täyttänyt kyselyn, tallenna se samalla nimellä ja lähetä minulle sähköpostin liitetiedostona. Vastaukset kulkevat mukana.

Seuraavassa pitää valita, onko lauseen esittämä tilanne tai väittämä lähinnä järkeenkäypä vai outo. Tarkoitus ei ole miettiä tilannetta vain omalla kohdallasi, vaan myös yleisemmin. Lauseita on 124 kappaletta. Mikäli haluat kommentoida joitain kohtia, niin lopussa on vapaa kenttä. ”En millään keksi” – vastauksia on suotavaa käyttää vain, mikäli vaaka ei meinaa kallistua hiukkaakaan kummallekaan puolelle.

Tarvitsen kyllä ikäsi:

Pidän käsilaukussani yleensä kaulinta	**en millään keksi**
Lentotukialuksen kannella on lukuisia linja-autoja	**en millään keksi**
Rahanhankkimisessa auttaa yleensä työnteko	**en millään keksi**
Ystäväni kulkee yleensä työmatkansa junalla	**en millään keksi**
Laitan yleensä leivän päälle sammakoita	**en millään keksi**
laivamme oli viimeinkin saapumassa keittiöön	**en millään keksi**
Karateohjaajana toimi eräs tonttu	**en millään keksi**
Armeijan uusi suojaväri oli ruskea	**en millään keksi**
Kiinalaisessa taiteessa esiintyy usein meloni	**en millään keksi**
Eilen aamulla televisiosta tuli vain joku kummitus	**en millään keksi**

Sadonkorjuun aikaan poimimme talteen omenat	**en millään keksi**
Oppiakseni puolustautumaan aloin harrastaa shakkia	**en millään keksi**
Ennen muinoin pitkät matkat taitettiin hevosilla	**en millään keksi**
Juulian isä on ammatiltaan tutkija	**en millään keksi**
Lentotukialuksen kannella on lukuisia koptereita	**en millään keksi**
Armeijan uusi suojaväri oli vihreä	**en millään keksi**
Annoin vanhat aurinkolasini yhdelle miehelle	**en millään keksi**
Rahanhankkimisessa auttaa yleensä pistooli	**en millään keksi**
Minusta mukavin kotiaskare on tiskaaminen	**en millään keksi**
Unettomina iltoina alan usein pelata tietokonetta	**en millään keksi**
Lapseni kulkee kouluun raketilla	**en millään keksi**
En haluaisi olla töissä vaan merillä	**en millään keksi**
Naapurini sai eilen saaliiksi tähden	**en millään keksi**
Mies on heittämässä tikkaa	**en millään keksi**
Tyypillistä - ruokaani on lennähtänyt kirves	**en millään keksi**
Minusta mukavin kotiaskare on teurastus	**en millään keksi**
Markku kantaa sylissään autoa	**en millään keksi**
Päivän postissa oli kuorma-auto	**en millään keksi**
Karateohjaajana toimi eräs poika	**en millään keksi**
Annoin rakkaalleni lahjaksi runon	**en millään keksi**
Perheemme on jo pitkään asunut kuussa	**en millään keksi**
Entinen luokkatoverini Maija on nykyään kiireinen	**en millään keksi**
Laitan yleensä kahviini hiiren	**en millään keksi**
Siivotessani löysin sängyn alta vaatteita	**en millään keksi**
Karateohjaajana toimi eräs nainen	**en millään keksi**
Oppiakseni puolustautumaan aloin harrastaa golfia	**en millään keksi**
Entinen luokkatoverini Maija on nykyään vamppyyri	**en millään keksi**
Laitan yleensä leivän päälle juustoa	**en millään keksi**
Naapurimme ovat rakentaneet pihalleen kirkon	**en millään keksi**
Hankimme tyttärellemme lemmikiksi lehmän	**en millään keksi**
Lapseni kulkee kouluun kävellen	**en millään keksi**
Tyypillistä - ruokaani on lennähtänyt lehti	**en millään keksi**
Jo dinosaurukset osasivat lentää	**en millään keksi**
Kesällä on mukava istua iltaa autossa	**en millään keksi**
Myöhästyin koska jäin jumiin faksiin	**en millään keksi**
Hankimme tyttärellemme lemmikiksi kanin	**en millään keksi**
Ajattelimme lähteä lomalle avaruuteen	**en millään keksi**
Vangilla on sellissään lumiukko	**en millään keksi**
Jäätiköllä vaeltaessamme törmäsimme ritariin	**en millään keksi**
Annoin vanhat aurinkolasini yhdelle naiselle	**en millään keksi**
Armeijan uusi suojaväri oli keltainen	**en millään keksi**
Koiramme ajaa usein takaa postiljoonia	**en millään keksi**
Syön nykyään harvemmin lempiruokaani pizzaa	**en millään keksi**
Syön nykyään harvemmin lempiruokaani kanaa	**en millään keksi**
Entinen luokkatoverini Maija on nykyään rauhallinen	**en millään keksi**
Kimmo piirsi koulussa kuvan seeprasta	**en millään keksi**
Tyypillistä - ruokaani on lennähtänyt kärpänen	**en millään keksi**
Japanilaisessa taiteessa esiintyy usein tulivuori	**en millään keksi**
Karateohjaajana toimi eräs simpanssi	**en millään keksi**
Minusta mukavin kotiaskare on imuroiminen	**en millään keksi**

Tänään valmistetaan ruoaksi hattu	**en millään keksi**
Siivotessani löysin sängyn alta diplomaatin	**en millään keksi**
laivamme oli viimeinkin saapumassa avomerelle	**en millään keksi**
Olen tottunut käyttämään kirjoja laskuvarjona	**en millään keksi**
Vangilla on sellissään linnunpesä	**en millään keksi**
Ajattelimme lähteä lomalle vankilaan	**en millään keksi**
Siivotessani löysin sängyn alta kirjan	**en millään keksi**
Vangilla on sellissään hiiri	**en millään keksi**
Töissä käyttämäni tietokone on sairastunut	**en millään keksi**
Setäni kasvattaa maatilallaan lampaita	**en millään keksi**
Naapurini sai eilen saaliiksi kalan	**en millään keksi**
Naapurimme ovat rakentaneet pihalleen uima-altaan	**en millään keksi**
Ystäväni kulkee yleensä työmatkansa autolla	**en millään keksi**
Setäni kasvattaa maatilallaan palmuja	**en millään keksi**
Perheemme on jo pitkään asunut puussa	**en millään keksi**
Kaupungin yllä leijui pitsa	**en millään keksi**
Kesällä on mukava istua iltaa terassilla	**en millään keksi**
Uusi työtoverimme on ankka	**en millään keksi**
Jäätiköllä vaeltaessamme törmäsimme jääkarhuun	**en millään keksi**
Taloyhtiössämme ramppaa jatkuvasti poliisi	**en millään keksi**
Tänään valmistetaan ruoaksi kalkkunaa	**en millään keksi**
Unettomina iltoina alan usein pelata pasianssia	**en millään keksi**
Joidenkin poliisien henkilökohtainen ase on lyijykynä	**en millään keksi**
Ennen muinoin pitkät matkat taitettiin matolla	**en millään keksi**
Uusi työtoverimme on hyökkäävä	**en millään keksi**
Eräs tuntemani poliisi syö usein kenkiä	**en millään keksi**
Minä ja vaimoni olemme ajatelleet hankkia omakotitalon	**en millään keksi**
Valtion pitäisi satsata enemmän curlingiin	**en millään keksi**
Viimeaikoina olen tavannut herätä väsyneenä	**en millään keksi**
Naapurini sai eilen saaliiksi peuran	**en millään keksi**
Taloyhtiössämme ramppaa jatkuvasti vuohia	**en millään keksi**
Unettomina iltoina alan usein pelata jääkiekkoa	**en millään keksi**
Kaupungin yllä leijui ilmalaiva	**en millään keksi**
Nykyään soitan usein kengässä	**en millään keksi**
laivamme oli viimeinkin saapumassa vuorelle	**en millään keksi**
Minä ja vaimoni olemme ajatelleet hankkia orjan	**en millään keksi**
Annoin rakkaalleni lahjaksi kukkia	**en millään keksi**
Eilen aamulla televisiosta tuli vain joku piirretty	**en millään keksi**
Kiinalaisessa taiteessa esiintyy usein kokki	**en millään keksi**
Kummitätini polttaa joskus kuistillaan tupakkaa	**en millään keksi**
Olohuonetta piristää kummasti hankkimani matto	**en millään keksi**
Laitan yleensä leivän päälle makkaraa	**en millään keksi**
Myöhästyin koska jäin jumiin tulppaaniin	**en millään keksi**
Viimeaikoina olen tavannut herätä pirteänä	**en millään keksi**
Armeijan uusi suojaväri oli pinkki	**en millään keksi**
Mies on heittämässä kettua	**en millään keksi**
Koiramme ajaa usein takaa kissaa	**en millään keksi**
Naapurimme ovat rakentaneet pihalleen tehtaan	**en millään keksi**
Kotka on saanut saaliikseen rotan	**en millään keksi**
Taloyhtiössämme ramppaa jatkuvasti marssilaisia	**en millään keksi**

Kotka on saanut saaliikseen lokin	**en millään keksi**
Pienokaisemme oppi kesällä lentämään	**en millään keksi**
Hankimme tyttärellemme lemmikiksi koiran	**en millään keksi**
Kotka on saanut saaliikseen maapallon	**en millään keksi**
Ajattelimme lähteä lomalle vuorille	**en millään keksi**
Mikko notkui baarissa seuranaan eräs humalainen	**en millään keksi**
Lentotukialuksen kannella on lukuisia seeproja	**en millään keksi**
Sadonkorjuun aikaan poimimme talteen pullot	**en millään keksi**
Juulian isä on ammatiltaan rakennusmies	**en millään keksi**
Jäätiköllä vaeltaessamme törmäsimme budhaan	**en millään keksi**
Kimmo piirsi koulussa kuvan itsestään	**en millään keksi**
Kesällä on mukava istua iltaa luolassa	**en millään keksi**
Opettaja piti tämän päivän oppitunnin seisaaltaan	**en millään keksi**
Nykyään soitan usein pyöräillessä	**en millään keksi**

Alla olevaan suorakulmioon voi kirjoittaa kommentteja. Mikäli jatkat edellistä juttua, muista painaa ensin nuolta oikealle, ettei edellinen teksti häviä.

Appendix D: Cloze probability rating form for sentences and pictures (1/4)

Tämä on sanavalintaosio. Tarkoitus on keksiä lauseille yhdestä sanasta koostuvat kuvan kanssa yhteensopivat lopetukset. Halutessasi voit ilmoittaa myös kaksi tai kolme vaihtoehtoista lopetusta (eroteltuna pilkulla tms.). Taivutusmuoto on vapaa. Sinun pitää luultavasti hyppelehtiä Wordin ja jonkin kuvaselaimen välillä. Kuvien pitäisi avautua järkevissä ohjelmissa numerojärjestyksessä 1-62. Vastattuasi tallenna ja lähetä minulle liitetiedostona. Lopussa on taas tilaa vapaille kommenteille.

Tarvitsen kyllä ikäsi:

Numerot vasemmalla vastaavat kuvien nimiä.

1	Pidän käsilaukussani yleensä
2	Lentotukialuksen kannella on lukuisia
3	Rahanhankkimisessa auttaa yleensä
4	Ystäväni kulkee yleensä työmatkansa
5	Laitan yleensä leivän päälle
6	laivamme oli viimeinkin saapumassa
7	Karateohjaajana toimi eräs
8	Armeijan uusi suojaväri oli
9	Kiinalaisessa taiteessa esiintyy usein
10	Eilen aamulla televisiosta tuli vain joku
11	Sadonkorjuun aikaan poimimme talteen
12	Oppiakseni puolustautumaan aloin harrastaa
13	Ennen muinoin pitkät matkat taitettiin
14	Juulian isä on ammatiltaan
15	Lentotukialuksen kannella on lukuisia
16	Armeijan uusi suojaväri oli

17	Annoin vanhat aurinkolasini yhdelle
18	Rahanhankkimisessa auttaa yleensä
19	Minusta mukavin kotiaskare on
20	Unettomina iltoina alan usein pelata
21	Lapseni kulkee kouluun
22	En haluaisi olla töissä vaan
23	Naapurini sai eilen saaliiksi
24	Mies on heittämässä
25	Tyypillistä - ruokaani on lennähtänyt
26	Minusta mukavin kotiaskare on
27	Markku kantaa sylissään
28	Päivän postissa oli
29	Karateohjaajana toimi eräs
30	Annoin rakkaalleni lahjaksi
31	Perheemme on jo pitkään asunut
32	Entinen luokkatoverini Maija on nykyään
33	Laitan yleensä kahviini
34	Siivotessani löysin sängyn alta
35	Karateohjaajana toimi eräs
36	Oppiakseni puolustautumaan aloin harrastaa
37	Entinen luokkatoverini Maija on nykyään
38	Laitan yleensä leivän päälle
39	Naapurimme ovat rakentaneet pihalleen
40	Hankimme tyttärellemme lemmikiksi
41	Lapseni kulkee kouluun
42	Tyypillistä - ruokaani on lennähtänyt
43	Jo dinosaurukset osasivat
44	Kesällä on mukava istua iltaa
45	Myöhästyin koska jäin jumiin
46	Hankimme tyttärellemme lemmikiksi
47	Ajattelimme lähteä lomalle
48	Vangilla on sellissään
49	Jäätiköllä vaeltaessamme törmäsimme
50	Annoin vanhat aurinkolasini yhdelle
51	Armeijan uusi suojaväri oli
52	Koiramme ajaa usein takaa
53	Syön nykyään harvemmin lempiruokaani
54	Syön nykyään harvemmin lempiruokaani
55	Entinen luokkatoverini Maija on nykyään
56	Kimmo piirsi koulussa kuvan
57	Tyypillistä - ruokaani on lennähtänyt
58	Japanilaisessa taiteessa esiintyy usein
59	Karateohjaajana toimi eräs
60	Minusta mukavin kotiaskare on
61	Tänään valmistetaan ruoaksi
62	Siivotessani löysin sängyn alta

Vapaat kommentit:

Appendix E: Cloze probability form for sentences in isolation

Ikä: Sukupuoli:

Jo dinosaurukset osasivat	
Annoin vanhat aurinkolasini yhdelle	
Töissä käyttämäni tietokone on	
Pidän käsilaukussani yleensä	
Jäätiköllä vaeltaessamme törmäsimme	
Karateohjaajana toimi eräs	
Mies on heittämässä	
Joidenkin poliisien henkilökohtainen ase on	
Lapseni kulkee kouluun	
Kimmo piirsi koulussa kuvan	
Oppiakseni puolustautumaan aloin harrastaa	
En haluaisi olla töissä vaan	
Kiinalaisessa taiteessa esiintyy usein	
Kaupungin yllä leijui	
Tyypillistä - ruokaani on lennähtänyt	
Japanilaisessa taiteessa esiintyy usein	
Armeijan uusi suojaväri oli	
Ajattelimme lähteä lomalle	
Syön nykyään harvemmin lempiruokaani	
Laitan yleensä leivän päälle	
Lentotukialuksen kannella on lukuisia	
Mikko notkui baarissa seuranaan eräs	
Ystäväni kulkee yleensä työmatkansa	
Hankimme tyttärellemme lemmikiksi	
Nykyään soitan usein	
Eräs tuntemani poliisi syö usein	
Sadonkorjuun aikaan poimimme talteen	
Entinen luokkatoverini Maija on nykyään	
Markku kantaa sylissään	
Uusi työtoverimme on	
Vangilla on sellissään	
Annoin rakkaalleni lahjaksi	
Olohuonetta piristää kummasti hankkimani	
Naapurini sai eilen saaliiksi	
Eilen aamulla televisiosta tuli vain joku	
Kummitätini polttaa joskus kuistillaan	
Siivotessani löysin sängyn alta	
Juulian isä on ammatiltaan	
Viimeaikoina olen tavannut herätä	
Perheemme on jo pitkään asunut	
Opettaja piti tämän päivän oppitunnin	
Kesällä on mukava istua iltaa	
Ajattelin ostaa uuden	
Minä ja vaimoni olemme ajatelleet hankkia	
Olen tottunut käyttämään kirjoja	

Rahanhankkimisessa auttaa yleensä	
Minusta mukavin kotiaskare on	
Ennen muinoin pitkät matkat taitettiin	
Taloyhtiössämme ramppaa jatkuvasti	
Koiramme ajaa usein takaa	
Laitan yleensä kahviini	
Pienokaisemme oppi kesällä	
Pukeudun lomalla yleensä	
Myöhästyin koska jäin jumiin	
Naapurimme ovat rakentaneet pihalleen	
Setäni kasvattaa maatilallaan	
laivamme oli viimeinkin saapumassa	
Tänään valmistetaan ruoaksi	
Unettomina iltoina alan usein pelata	
Valtion pitäisi satsata enemmän	
Päivän postissa oli	
Kotka on saanut saaliikseen	

Appendix F: Instructions

Ohje kokeeseen

Tehtäväsi on arvioida kuvan ja lauseen yhteensopivuutta. Yhteensopivuutta ei ole kätketty piilomerkityksiin tai äänensävyyn. Kuvat esitetään näytöllä ja niiden kanssa yhtäaikaisesti kuulokkeista lauseet. Kuva tulee näkyviin ennen lauseen alkua. Mikäli kuva ja lause:

- sopivat yhteen, paina hiiren vasenta näppäintä
- mikäli ne eivät sovi yhteen, paina oikeata. [or vice versa]

Vastausta ei saa antaa ennen kuin kuva poistuu näytöltä hetki lauseen loppumisen jälkeen. Vastauksen antamiseen on aikaa kolme sekuntia. Hiirtä pidetään sylissä. Oikeaa näppäintä painetaan oikealla kädellä ja vasenta vasemmalla. Mikäli et ehdi vastata ennen kuin seuraava kuva ilmestyy näytölle, keskity uuteen arviointiin ja unohda edellinen.

Aivosähkökäyrä peittyy pienenkin lihastoiminnan aiheuttaman sähkökentän alle. Kiinnostuksen kohteena on erityisesti aikaikkuna aina viimeisen sanan kohdilla. Siksi olisi toivottavaa, että suorittaisit silmien räpyttelyn, asennon korjaamisen ja esimerkiksi nieleskelyn sen jälkeen, kun kuva poistuu näytöltä. Tämän jälkeen olisi taas hienoa, mikäli pystyt seuraavan lauseen kuluessa saavuttamaan taas rennon, liikkumattoman ja keskittyneen tilan ennen kuin viimeinen sana alkaa. Tällöin olisi jopa suotavaa pitää katse kohdistettuna yhteen pisteeseen. Heilumisia ja räpyttelyjä tietysti tapahtuu, vaikka mitä yrittäisi, joten ei niistä tarvitse turhia stressata.

Ärsykkeet on jaettu kolmeen noin 13 minuuttia kestävään osaan, joiden välissä on mahdollista pitää hetki taukoa.